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The 'ENGLISH ELECTRIC' Journal

VOLUME SEVENTEEN · NUMBER THREE

SEPTEMBER 1961

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CONTENTS

Main articles :—

MULTI-ROPE FRICTION WINDING AT WEARMOUTH COLLIERY, *by A. White, A.M.I.E.E., Mining Division* page 4

THE ROLE OF THE H.R.C. FUSE IN THE PROTECTION OF LOW AND MEDIUM VOLTAGE SYSTEMS, *by E. Jacks, M.I.E.E., Chief Engineer, Fusegear Division* page 22

A GAS TURBINE FOR PEAK LOAD OPERATION AT THE UNIVERSITY OF ALBERTA .. .. page 45

Other items :—

Frontispiece : Pump motors at Dundee oil depot .. .. page 2

Editorial .. .. page 3

A.C/D.C. welding equipment: a new range, *by R. H. Boughton, M.Inst.W., Manager, Welding Equipment Division* pages 20 & 21

Centre Plate : New British cable ship .. .. pages 24 & 25

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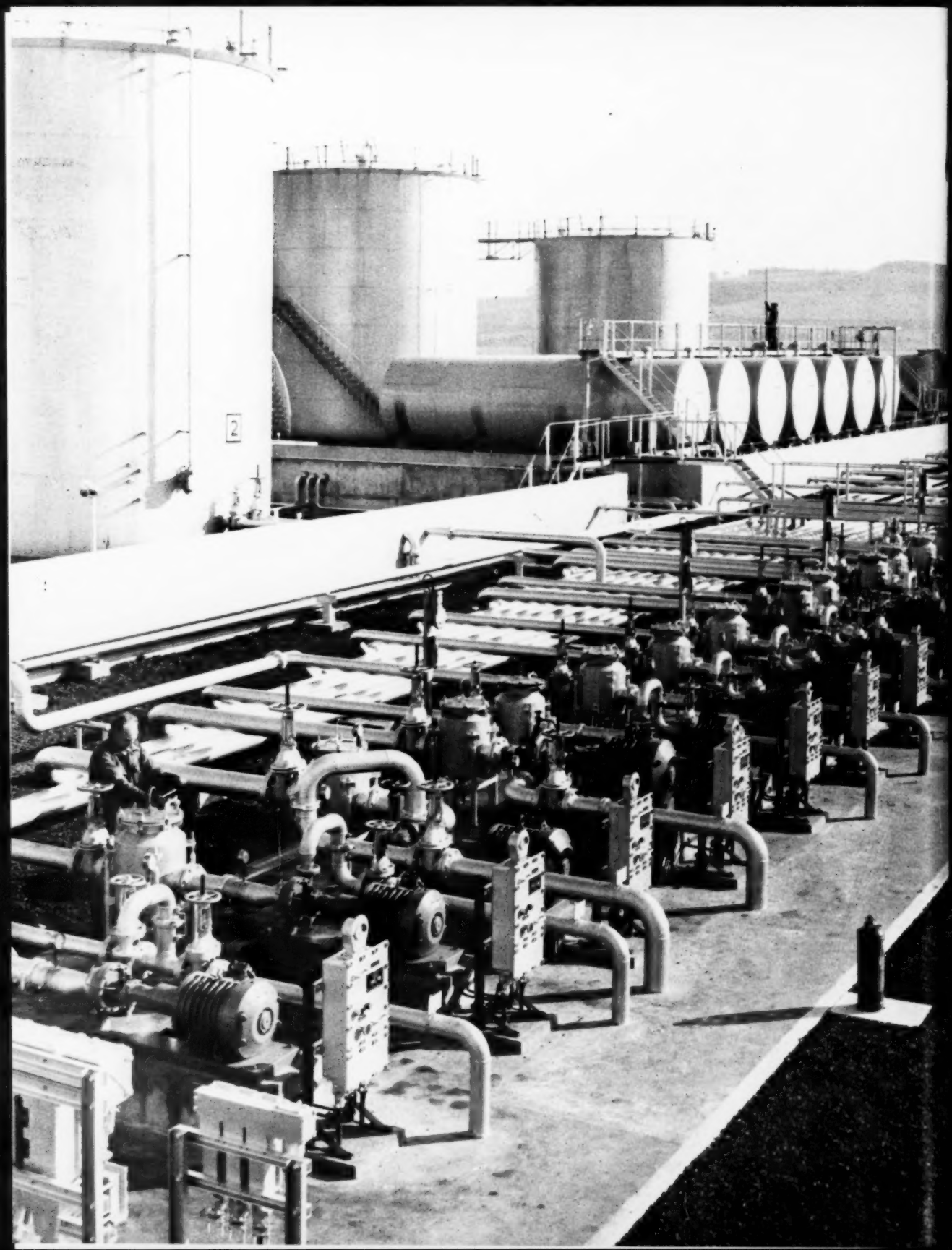

Editorial

SUCCESS in the field of friction mine winders is reflected by the description in this issue of the Company's equipments at Wearmouth colliery, County Durham. It was here that the first a.c. multi-rope winding equipment in Britain was put into service at the 'A' shaft in 1957. The first multi-rope friction winder of all in the U.K. was also an 'English Electric' installation, commissioned at Ryhope colliery the previous year, this being a d.c. winder with Ward Leonard control.

An outstanding achievement by the Company is the winning of the order for the switchgear for the first switching station of the Central Electricity Generating Board's projected 400kV supergrid. This is to be installed at the West Burton, Nottinghamshire, power station for which four 'English Electric' 500MW turbo-alternator sets are at present on order, as reported in our June 1961 issue. The present order comprises thirteen 35,000MVA air blast circuit breakers, eight of which will be rated at 4,000A and five at 2,000A, together with power-operated isolators and other apparatus to form a complete duplicate-busbar switching station.

To be first shows initiative, but it is good to be able to report here also an impressive record of reliability in service. This has been achieved by an EM27 gas turbine at the Esso Petroleum Company's refinery at Fawley, Hampshire. This machine (the same design as that in the Alberta installation described in this issue) commenced operation on the 25th November, 1958, and has since returned a measured availability factor of better than 99·7% in the 21,500 hours running time up to July of this year. During this period it ran non-stop for nearly six months. The turbine is fuelled by refinery gases.

OIL PUMP DRIVES *'English Electric' squirrel-cage flameproof motors (group* II*) driving pumps at the main pump platform of the Scottish Oils and Shell-Mex Ltd Dundee depot, Scotland. Totally-enclosed fan-cooled machines ranging from* 3¾ *hp to* 25 *hp have been supplied for this installation.* [*Photo: Shell-Mex & B.P. Ltd.*]

Multi-rope Friction Winding at Wearmouth Colliery

by A. WHITE, A.M.I.E.E., Mining Division

The consecutive installations at the A, C and D shafts of this colliery symbolize the general technical development that is leading to ever more efficient coal winning.

WEARMOUTH COLLIERY is in the centre of the Borough of Sunderland, one-and-a-half miles from the mouth of the River Wear, the eastern boundary of its workings extending three miles beyond the coastline. Sinking of the 'A' and 'B' shafts started in 1826, and, after stopping back the influx of water that had impeded sinking operations, a depth of 1,000 ft was reached without winning any valuable bed of coal. Sinking operations continued, however, and in 1833 the 5/4 seam was reached. Discovery of the Maudlin seam at 1,600 ft followed one year later, and finally the Hutton seam was reached at 1,716 ft in 1846. At this time the colliery was described as "the deepest mine in the world". In 1864 a bore hole was put down from the Hutton seam, which proved the Harvey seam at a further depth of 178 ft.

Fig. 1—The changing face of Wearmouth colliery (National Coal Board, Durham Division). Towers housing the modern friction winders of 'A' and 'C' shafts flank the headframe of 'B' shaft, now almost a hundred years old

The 'C' shaft sinking was started in 1907 and reached the Harvey seam in 1910 at a depth of 1,852 ft. A brattice curtain dividing the shaft into two compartments was installed and the 18 ft dia shaft was used as both upcast and downcast for ventilation of the mine.

After supplying coal for home and overseas markets for over 120 years, Wearmouth again became the site of pioneering when, in September 1957, the first a.c. multi-rope winding equipment in Britain was put into service at the 'A' shaft. This was followed in September, 1958, by the commissioning of the Ward-Leonard, semi-automatic friction winder at the 'C' shaft. (Identical 'English Electric' equipments were installed at Westoe Colliery, November, 1957, and Ryhope colliery, September, 1956—the latter the first multi-rope friction winder to be commissioned in the U.K.)

It is further proposed that at the recently completed 24 ft dia 'D' shaft for fully automatic skip winding, friction drive shall again be employed.

In replacing the winders at the 'A' and 'C' shafts, multi-rope friction drives were chosen after an investigation by National Coal Board engineers had revealed their economic, safety and operational advantages. Limitations on load-per-wind imposed by non-availability, and the problem of handling ropes, are relieved by the use of a number of smaller ropes, which at the same time contribute substantially to safety. The small diameter wheel considerably reduces inertia and there is no question, as in the case of drum winding, of a drum of sufficient width to accommodate the full shaft depth of rope. A more efficient winding system is obtained, and the absence of direct rope anchorage at the drive reduces the potential danger in the event of overwinding. Indirect economic advantage is also gained, in tower-mounted installations, by the release of ground at a premium in close proximity to the mine shaft.

In friction winding, of course, it is necessary to avoid slip under operational conditions. It is therefore required by statute in the U.K. that the ratio of rope tensions be so limited that there is no slip when the coefficient of friction is 0·2. In practice the coefficient is in fact much higher. The static ratio of tensions is considerably reduced by balance ropes slung to connect the undersides of the conveyances.

'A' SHAFT EQUIPMENT

For the 'A' shaft, which is designed to handle men and materials from the three underground levels, a conventional manual-controlled 500 hp geared a.c. equipment incorporating the compensated system of dynamic braking has been adopted. The reinforced concrete tower, constructed on the main pillars of the old ventilation chimneys, houses the winder and control equipment on two floors.

The 5½-ton, double-deck cage and 8 ton counterweight are directly suspended by four ¾ in dia, locked-coil winding ropes from a 5 ft dia wood-lagged friction wheel. A flat balance rope of equal weight to the aggregate of the winding ropes has been used, and rope guides are provided for the cage and counterweight, with rigid receiver frames at the shaft extremities. The steel frames are terminated by taper guides integral with close-pitch racks which, together with shoes lined with friction material, form the arrestor assembly.

In the event of over-winding the cage, initial contact is made by the counterweight with the pit bottom arrestors to increase the ratio of rope tensions at the sheave and thus to reduce the potential stresses when the ascending conveyance is arrested. Following this, four solid hooks, situated at the four corners of the cage top enter the headgear arrestors. Spring loaded plungers in the headgear arrestors engage with the cage hooks and additional plungers engage with the surface racks, thus preventing free falling of the cage in the event of rope fracture. Supplementary braking is applied by resisting forces developed as the arrestors (both surface and underground) are driven along the tapered section of the guides towards the bumping beams. A generally similar arrangement is provided in case the counterweight is over-wound.

The winder

The friction wheel drive incorporates a composite gear box. The latter has the feature, necessary for tower winding, that mal-alignment of the drive, resulting from differential deflections in the supporting structure, is accommodated in the low speed shafting. This takes the form of quill and torsion shafts connected at the remote end by a gear-type coupling. A second gear coupling connects the torsion and friction wheel shafts. The wheel, keyed to the quill shaft, is engaged by a solid forged pinion to give a reduction of 4·37 : 1. The drive is completed by a rubber block coupling between the pinion and motor shafts to absorb the torsional shock loads. To produce the designed rope speed of 35 ft/sec, the 600 r.p.m. (synchronous) winder motor drives the wheel at 133 r.p.m.

High-pressure hydraulic spring brakes are employed, arranged as four independent units. These are applied to paths fabricated integral with the drum and lined with renewable cast iron segments. The brake control system is so arranged that, in the event of emergency application, the shoe clearance is taken up instantaneously and thereafter the rate of build-up to emergency braking torque is restrained. This has effectively limited the transient disturbances which would otherwise be induced in the suspended system by high-speed brake application.

An auxiliary drive, taken from the drum shaft, incorporates a composite unit, designed to compensate automatically for rope 'creep', (the relative displacement between winding ropes and friction wheel created by change in extension in the rope as it passes over the sheave). This compensating unit, described later, transmits the drive to the overspeed controller and dial-type depth indicator, so that manual adjustment of these distance-measuring features is unnecessary.

Reversal of the 5·5 kV slipring induction motor is facilitated by a d.c.-operated, air-break stator reverser, an extension of which carries the dynamic braking contactors. Ancillary controls and circuit distribution equipment are centralised in a multi-unit cubicle-type control board mounted adjacent to the reverser enclosure screen.

The lower floor accommodates the driver's platform, positioned to give a direct view of the winding ropes as they pass from the air-lock to the friction wheel. Additional equipment on this floor includes the h.v. switchboard, position/time servo-operated liquid controller, brake hydraulic supply unit and static dynamic braking supply equipment. The comprehensive safety and protective features include interlocking of the winder with the shaft gates and loading platforms.

'C' SHAFT EQUIPMENT

At the 'C' shaft a three-decked cage operating against a counterweight has been adopted (Fig. 2) for coal drawing from the three levels to produce an output of 290 tons/hr based on the 1,872 ft level. Each cage deck accommodates four 14 cwt tare, 26 cwt capacity tubs, giving a total payload of 15 tons, 12 cwt. With the selected 29 ton counterweight, based on the cage weight of 17 tons plus half gross load, a maximum out-of-balance of 12 tons obtains under maximum load and empty cage conditions. To obtain the requisite factor of safety, four $1\frac{3}{8}$ in dia locked-coil winding ropes are employed. The ropes are terminated in wedge-type cappels directly fixed to the cage and secured to the counterweight through spring suspension gear arranged for continuous take-up. Twin flat balance ropes with an aggregate weight of 19·13 lb/ft, equivalent to that of the winding ropes, make up the maximum total suspended load of approximately 105 tons.

As in the case of the 'A' shaft equipment, rope guides are used, the arrestor arrangement also being identical. The adoption of rope guides has precluded the use of fixed shaft furnishings in close proximity to the cage path at the intermediate levels. All shaft equipment at these levels is therefore retracted by pneumatic rams to give free passage to the cage.

The tower

The 150 ft steel tower was constructed around the existing double headframe. Two main floors are

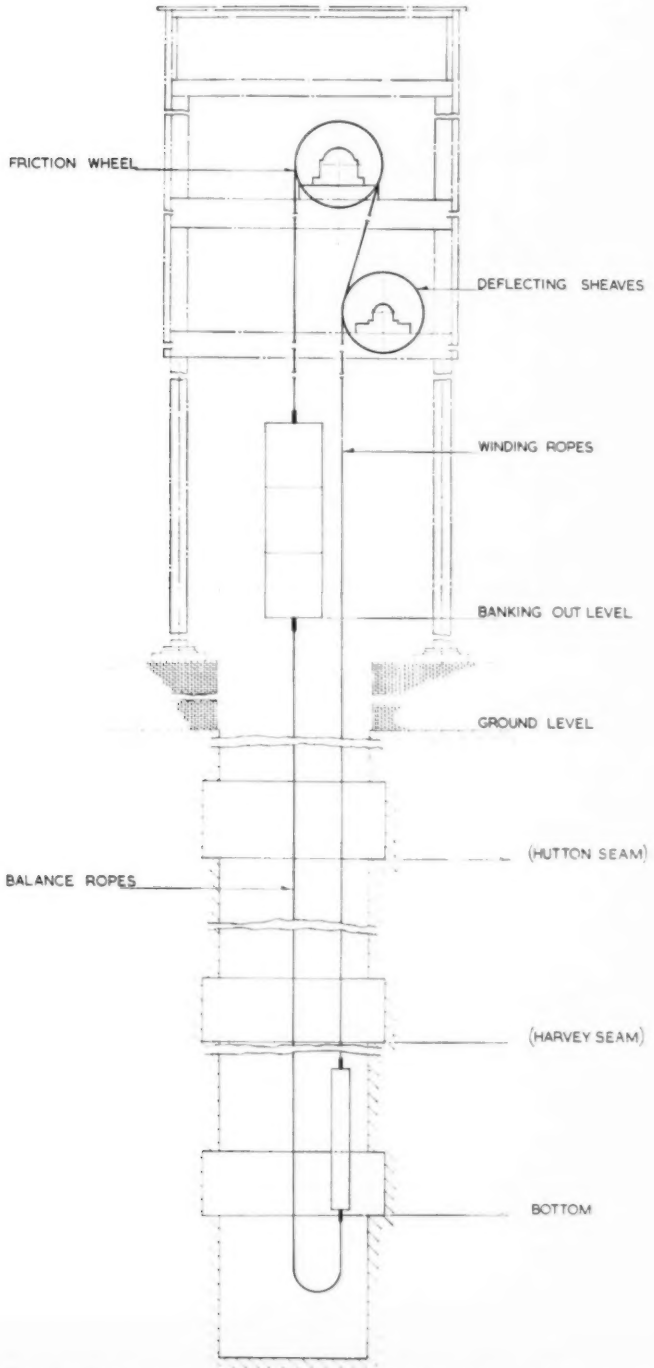

Fig. 2—The arrangement of the 'C' shaft friction winder

provided, the upper housing the friction wheel, motor and brake gear (Fig. 3), and the lower housing the deflecting sheaves, auxiliary drives and emergency manual control station.

The winder

The winder friction wheel is of fabricated steel with a cast steel boss. It is in halves, secured to its shaft by two tangential keys supplemented by shrink rings. The lagging takes the form of axially-mounted iroko timber blocks spanning the width of the friction wheel and grooved to 10′ 6″ dia at 12 in centres to accommodate the four winding ropes. Groove trimming, to equalise the four groove diameters and thus maintain equal tensions in the individual ropes, is facilitated by a motor-driven (multi-tool milling) cutter, mounted under the wheel.

Mild steel brake paths are fabricated integral with the wheel, and mate with zinc-bonded asbestos-lined shoes fitted to two pairs of post-type brakes. The braking force for each pair of shoes is obtained from an independent low pressure hydraulic engine working on the positive power principle. Both engines are supplied from a common hydraulic supply unit but each has its own pressure control valve, emergency solenoid and trip mechanism. Although, of necessity, the control valves share the same service control linkage, a flexible coupling has been introduced to permit the operation of one valve if the other seizes. The accumulator dead weights are so arranged that in the event of reduction or complete failure of oil pressure they are imposed on to rollers directly coupled to the posts, to produce the necessary reinforcing effort.

The forged-steel friction-wheel shaft, supported in two white-metal

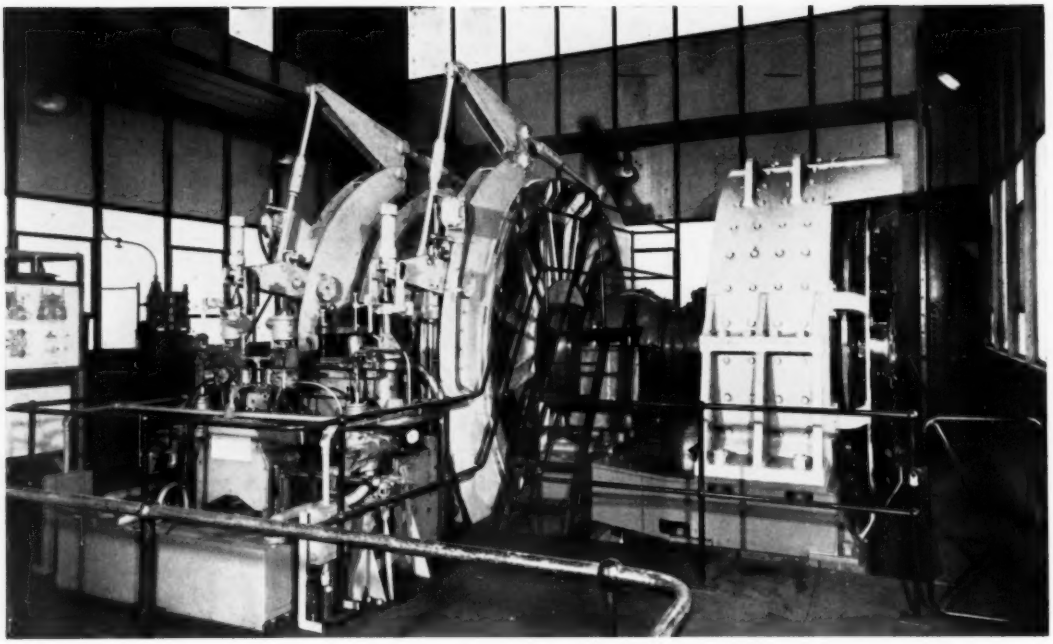

Fig. 3—The upper floor of 'C' shaft tower. The 2,000 hp semi-automatic friction winder

ring oil-lubricated 30" × 30" bearings, is extended at the driven end and directly coupled to the 17·5 ton overhung winder motor armature. The coupling, which is of special design for this arrangement, with halves solid with the wheel shaft and armature hub respectively, employs fitted bolts and radial torque keys.

A twenty-pole, 600 V d.c. motor drives the wheel, at a maximum speed of 73 r.p.m., developing 2,000 hp r.m.s./4,000 hp. peak. With a resultant rope speed of 40 ft/sec the required output is met by 9·75 sec linear acceleration followed by 9·75 sec graded acceleration, 27·57 sec at full speed, linear retardation for 14·63 sec and 35 sec decking (Fig. 4). The magnet frame, with separately-excited field windings, and the commutating and compensating windings, was transported in halves and assembled and connected in situ. The frame shares a U-shaped bedplate with the driven-end drumshaft bearing, the remote end bearing being secured to an independent soleplate.

On the lower floor, four 9'-6" dia deflecting sheaves are housed (Fig. 2), to guide the winding ropes to the cage centre line; one of these is keyed to the shaft, the remainder being free to rotate independently. Each sheave has laminated leather inserts located in its periphery, machined to the rope profile. White metal bearings, arranged for ring oil lubrication, support the deflector sheave shaft, which is extended at one end to accommodate a spur gear for the winder auxiliary drives. Of these auxiliary drives, the mechanical dial-type depth indicator and overspeed controller, comprising the distance-measuring features, are driven from the output of an automatic rope creep compensating device.

This floor also serves to accommodate the emergency manual control station. The station, which is used only for rope changing and other manoeuvres calling for close co-ordination between driver and engineer (e.g. grooving and statutory tests), takes the form of platform equipment. In addition to the speed control and brake levers, however, a changeover lever for selection of local or remote control is provided, all levers being provided with electrical locking. Cabinets,

housing the essential instruments, push buttons, indicating lamps and signalling equipment, together with the speed-reference potentiometer, complete the equipment.

The motor-generator house

A separate building, adjacent to the tower base, accommodates the main supply and control equipment (Fig. 5). Direct current for the winder motor is derived from a 750 r.p.m. synchronous motor-driven 1,600 kW variable-voltage generator. The salient-pole motor is capable of operating at unity power factor at the rated r.m.s. output of 1,400 hp, or alternatively at the 3,150 hp working peak. Arranged for reactor starting from the 5·5 kV supply, the machine drives its own exciter

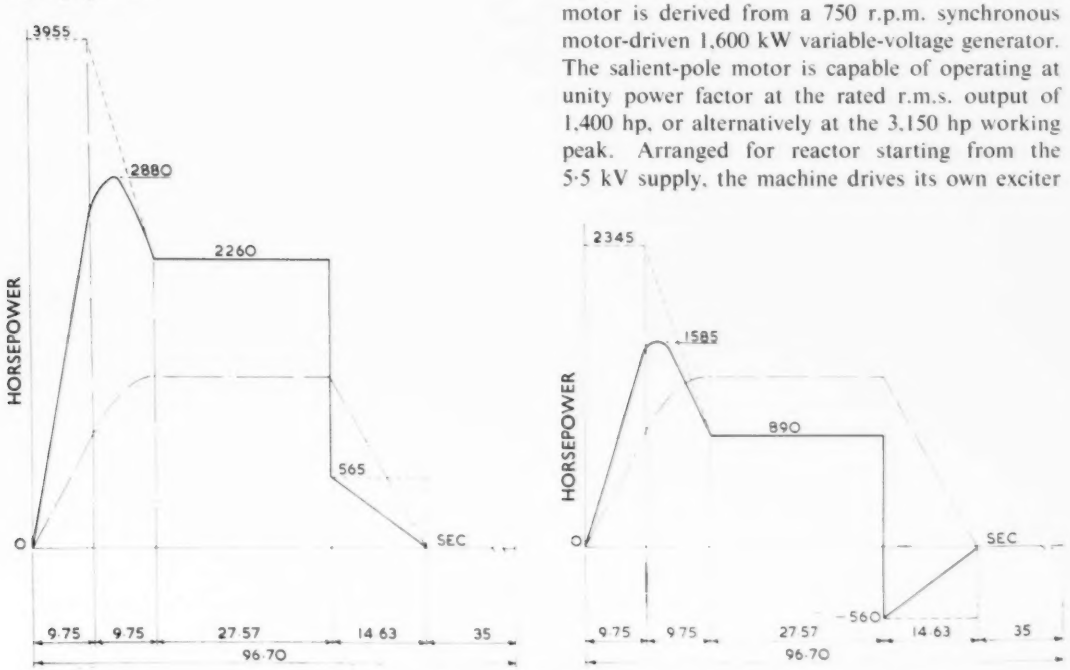

Fig. 4—The duty cycle diagram of 'C' shaft winder (Left) raising coal load, and (right) raising counterweight

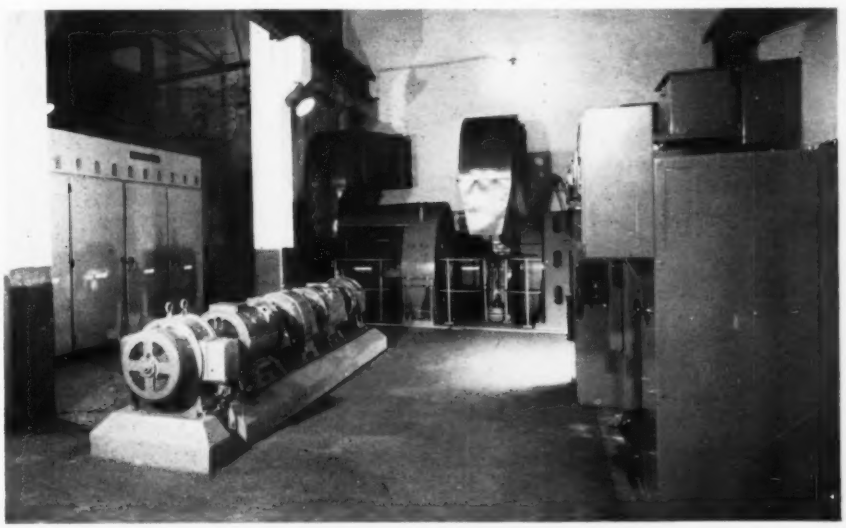

Fig. 5 — The 1,400 hp motor-generator set supplying the 'C' shaft winder and, in the foreground, rotating amplifiers and associated control equipment

through a flexible coupling. The generator is solidly coupled.

A multi-panel air-insulated switchboard with duplicate incoming feeders incorporates full protection to the synchronous motor and to the 50 kVA auxiliary transformer. A non-automatic circuit breaker is included for reactor short-circuiting, and the switchboard also accommodates the motor excitation control equipment.

Excitation for the variable-voltage generator is supplied from a small five-machine set consisting of a 25 hp squirrel-cage motor driving the generator exciter, the pilot exciter, the control exciter and the constant-voltage exciter. The a.c. auxiliaries, d.c. control and automatic control relays and contactors are housed in a multi-unit cubicle control board. The board, which is sectionalised, includes a unit forming the main circuit distribution centre for all outgoing control connections, the terminal boards being arranged in logical sequence to facilitate testing. Conveniently grouped monitoring instruments continuously indicate the condition of the circuits and expedite checking and adjustments. Cable interconnections are used throughout the installation, including the main d.c. connections, which comprise three 1 sq. in. single-core cables per pole.

Remote control stations

The main control station is positioned at bank to give the winding engineman/banksman unobstructed vision of cage loading and discharge. It incorporates manual, semi-automatic winding and mine-car handling control equipment. As will be seen from Fig. 6 the desk is so designed that change in angle of viewing the indicators is minimised and a centre recess allows a direct view of the cage landing position. The desk is equipped with the following fully interlocked levers :—speed control, brake and remote manual/emergency manual/semi-automatic winding selection. In addition to the instruments, signal indicators and indicating lamps, conveniently positioned switches are provided for initiation of automatic winding, deck changing, level selection and rams, and for overriding cage stops, rear stops and shaft gates control. Accurate indication of the cage position is provided by a Selsyn-operated depth indicator, supplemented by twin-pin lamps indicating 'cage in line' and 'deck in line' at the underground levels.

Floor mounting consoles at the shaft entrances (Fig. 7) provide automatic winding, car handling and signalling facilities at the intermediate levels and pit bottom. Controls for shaft platforms are

Fig. 6—The bank station (remote manual/semi-automatic control). Mine-car handling is also controlled from here, the decking level being visible beyond the control desk

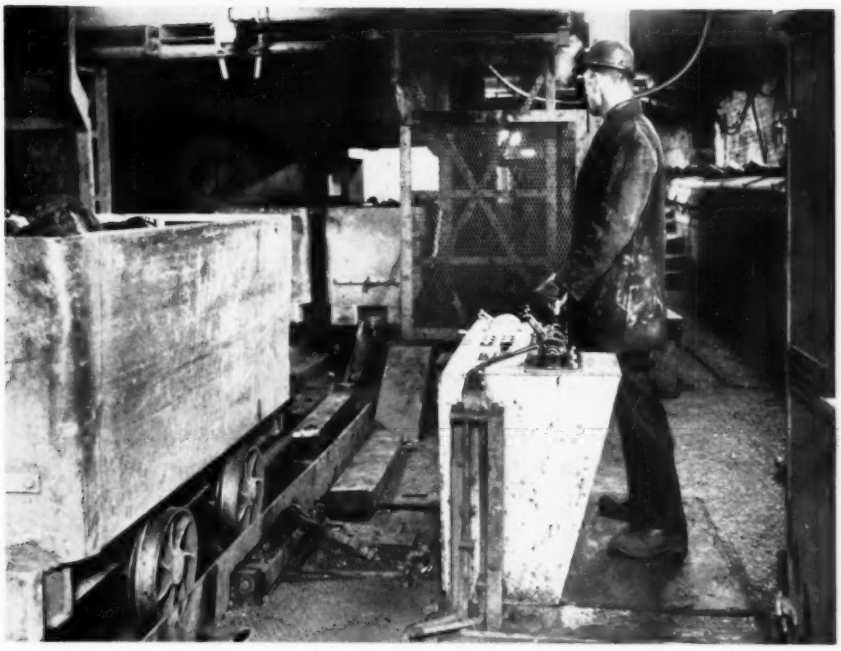

Fig. 7—One of the underground control stations

included on all consoles and additional controls for operation of the retractable in-line gear are also provided at the intermediate level stations. Circuit distribution centres are provided at each station to complete the overall pattern of sectionalised testing facilities.

Closed loop control

Close conformity to the speed/distance cycle, essential for automatic control, is consistently maintained by an electrical servo control incorporating a tuned series exciter. While allowing freedom of control to the driver within the safe limits of the equipment for manoeuvring under manual control, the system can automatically reproduce the designed winding cycle. This relieves the driver of fatigue and thus makes a considerable contribution to safety.

The control system (Fig. 8) provides :—

(*a*) Accurate steady-state speed control to maintain the winder speed substantially constant over the load range.

(*b*) Acceleration/retardation control to limit the demand on the equipment and to maintain the correct speed/distance relationship when the conveyance approaches the landing.

(*c*) Torque (Current) control to facilitate the build-up of holding torque prior to brake release and to limit the circulating current when the winder motor is stationary.

The speed control system

Under manual control the speed reference is obtained from a faceplate potentiometer mechanically coupled to the driver's lever. The output of this potentiometer is a scalar representation of the selected speed and is compared with the output of the speed-measuring network representing the actual winder speed. The difference indicates speed error and constitutes a correcting signal for actuating the control mechanism.

The comparison of selected against actual speed is made within the pilot exciter, which is designed to give its maximum saturated output with minimum speed error input. This output, which is substantially constant for speed error inputs greater than 15% of maximum speed, constitutes an acceleration or retardation signal. The signal

is fed into the control exciter, where it is amplified, and the integrated error passes to the generator exciter and the variable voltage generator, to adjust the winder motor armature voltage.

Acceleration/retardation control

In order to restrain the rate of correction, i.e. acceleration or retardation, the signal is opposed by a feedback signal obtained from the speed measuring network via an inductive coupler. This d.c. transformer produces an output proportional to the rate of change of its input. Thus in a similar manner to the speed control arrangement, the output of the pilot exciter is representative of the required acceleration and the feedback from the inductive coupler of the acceleration being produced. When the speed error and hence correcting signal become zero the steady-state speed condition is attained and the temperature-compensated control exciter maintains the motor armature voltage at the appropriate level under the influence of its series field.

The maximum power demand is reduced by graded acceleration, the acceleration being maintained constant up to approximately 65% maximum speed, and thereafter reducing linearly to zero at full speed. This is achieved by introducing resistance into the field circuits of the pilot exciter to so modify the exciter characteristic that a speed error in excess of 35% is required to produce its saturated output. The change from graded acceleration to linear retardation is automatically selected when retardation begins.

Adjustment of maximum speed and rate-of-change of speed can be, if required, effected by modifying the resistance in the appropriate feedback circuit.

Torque control

Application of the mechanical brake modifies the speed measuring network to effectively reconnect the feedback field of the pilot exciter across the winder motor armature. This provides an excitation proportional to the armature current and, in a similar manner to the action of the speed control, a steady current is obtained when this feedback is equal and opposite to the reference applied by the driver.

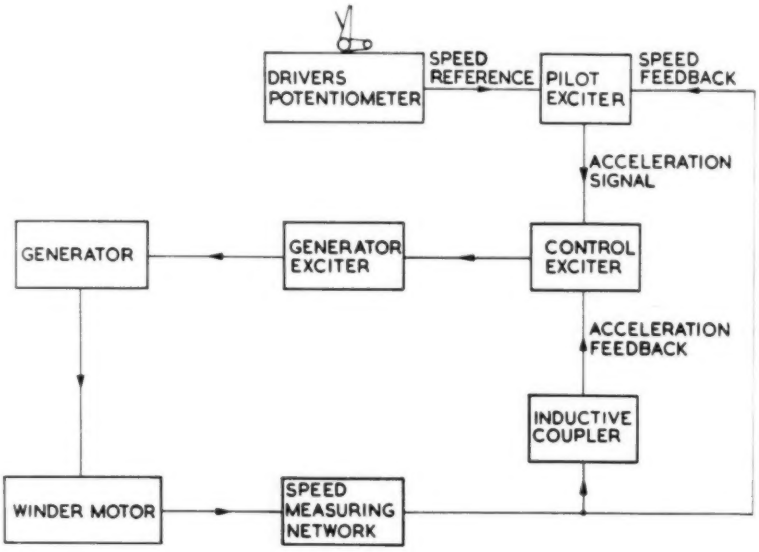

Fig. 8—Block diagram of the 'C' shaft winder control system

'Suiciding'

An additional function of the torque-measuring circuit is that of limiting the potential circulating current that results from the small residual voltage produced by the generator (due to field remanence). The circulating current produces an output from the measuring circuit to excite the pilot exciter, and passes a negative signal through the control loop to counteract the residual flux.

Operation

Three principal forms of winder control are available : emergency manual control, in the tower ; remote manual control, at bank ; and semi-automatic control, at bank and underground levels.

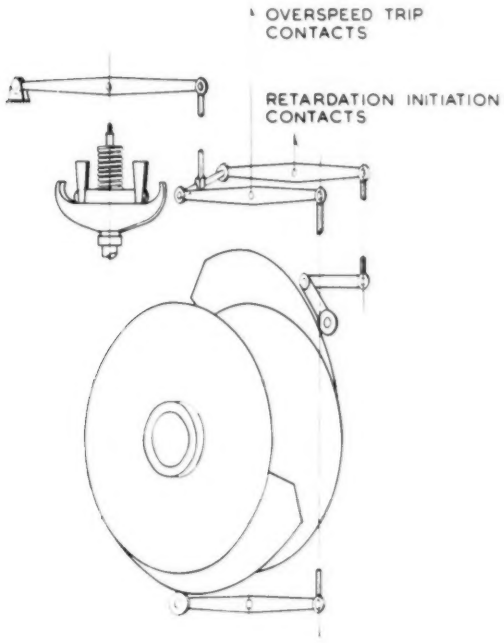

Fig. 9—The ' floating link ' mechanism for initiating retardation of the 'C' shaft winder

Manual control is provided at the tower emergency station for the purposes previously described, and also at a remote position at cage banking level for men-winding. Although these are electrically similar, remote manual control has necessitated the adoption of special electro-hydraulic features for brake control.

Under semi-automatic control, each wind is initiated by pushbutton operation to a pre-selected level. Initially, a fixed torque is applied to overcome the static out-of-balance preparatory to brake release, the system reverting to speed control with maximum reference when the brake shoes are clear of the paths. Maximum speed is maintained until the overspeed controller second floating link switch instantaneously reduces the reference to ' creep '. The winder then retards and is finally stopped by photo-electric, or alternatively magnetic proximity, devices.

Level selection

Selection of underground working levels, under the direct control of the winding engineman/banksman, is initiated by the operation of a desk-mounted selector switch and pushbutton. This energises the corresponding level-selection relay, automatically re-setting the control and protective features for retarding into the selected level.

To provide the required protection and control for multi-level cage and counterweight working, a modified controller was developed by Blacks Mining Equipment Limited of Bromley. This, device incorporates a conventional fixed dial for control and protection at the shaft extremities, and an electrically selected, hydraulically actuated, fully mobile dial for intermediate level working. Restriction to the selected distance limits is enforced by adjusting the angular displacement between the mobile and fixed dials.

Interlocking arrangements immobilise the winder when selection it taking place and prevent selection with the winder in motion.

Retardation initiation

The adoption of a pre-set rate-of-change control in the speed control system, as previously described, allows the use of a simple and accurate means for initiating retardation of the winder, this being an additional ' floating link ' mechanism incorporated in the overspeed controller (Fig. 9). The mechanism is similar to that used for overspeed protection and compares the governor output (actual speed) with that from a profiled cam plate (speed/distance reference). Electrical contacts actuated by the mechanism are arranged to operate when the actual and reference speeds coincide. By adopting a suitable cam profile, retardation is automatically initiated at the optimum distance from the landing for any approach speed, thus minimising the creep distance before landing.

Initiation of retardation into the chosen level is automatically pre-set on level selection and is effective for either direction of approach when winding to the intermediate levels. During normal deck-changing operations creep speed restriction is enforced, the system reverting to full-speed control at the start of the next cycle. These features are operative under manual and semi-automatic working, and discrimination is provided for men-winding that gives increased creep distance on approaching the landing. The retardation control and protection share the same means for de-sensitising during acceleration.

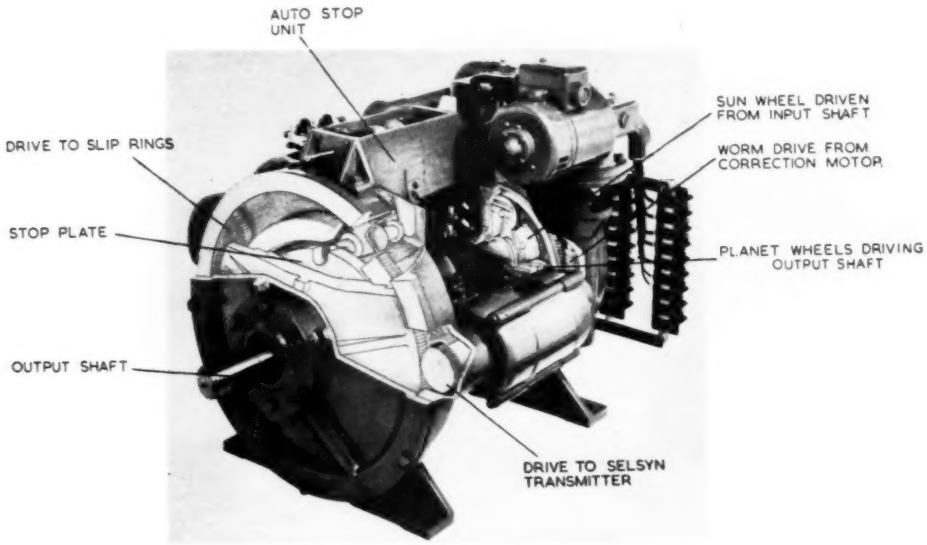

Fig. 10—The automatic rope creep compensating unit

Rope creep compensation

To counteract the effect of rope creep, i.e. differential movement of the rope and the sheave driving the distance-measuring features, a rope creep compensation unit is interposed in the auxiliary drive. This self-contained unit (Fig. 10) comprises an error-sensing slipring assembly and a motorised epicyclic correcting gear.

As the top deck of the cage comes level with the surface landing a magnetic proximity switch is operated to connect a supply to the sliprings. If the distance error exceeds 3 in, correction is automatically initiated to reduce the error to 0·25 in (maximum) and is accomplished in less than 5 sec. The available torque for compensation is adequate for re-synchronising the full complement of distance-measuring features and, in compliance with U.K. statutory requirements, correction is only possible when the winder brakes are fully applied.

The compensation unit

In the compensation unit, (Fig. 10), the input shaft from the winder is keyed to the sun wheel, the output shaft being keyed to the planet wheel carrier, and the correction motor clutched to the worm gear that engages the annulus. A spur gear provides the drive to the sliprings and a second spur drives the selsyn transmitter for the remote depth indicator. During winding the drive to the distance-measuring features is transmitted from the sun wheel to the planets, the annulus being held stationary by the low-efficiency, non-reversible worm gear. With the winder, and hence the sun wheel, held stationary by the winder brakes,

compensation is effected by the geared motor unit driving the annulus and planets through the worm gear.

Each of the slipring assemblies comprises a continuous and a segmented ring, the insulated segments being of low friction epoxy resin compound. The assemblies are provided with brush rocker arms carrying electrically connected brushes, the angular displacement of the rocker arms being adjustable to facilitate change in sensitivity. The direction and magnitude of distance error is a function of the displacement from the 'neutral' insulated ring segments. An error in excess of the pre-set minimum results in the lagging brush remaining on a conducting segment of the ring, closing a circuit to initiate the correction motor in the appropriate direction. Simultaneously, a relay connects the leading brush to the lagging brush and the sensitivity is changed to give minimum error (i.e. equivalent to $\frac{1}{4}$ in of rope movement).

To prevent overshoot of the drive on completion of correction, an automatically interposed stop is provided. This engages a slotted stop plate mounted on the Selsyn transmitter driving gear. The stop pin is automatically withdrawn after arresting the output shaft and is so interlocked as to prevent movement of the winder until the pin is completely clear of its register.

Winder safety and protection

The winder safety and protective features are allotted to one of two series tripping circuits, i.e. winder and electrical safety circuits, as appropriate. The former incorporates duplicate tripping contactors, the function of which is to initiate emergency mechanical braking and to re-set the servo control for electrical brake governing at the pre-set emergency retardation. Whereas this is sufficient in the case of winder overspeed and overwind trips, other conditions indicate failure of the servo. Such conditions result in operation of the electrical safety circuit which de-sensitises the servo and simultaneously trips the winder safety circuit.

THE PROPOSED 'D' SHAFT EQUIPMENT

To utilise fully the available shaft capacity, two friction winders, each of the same rating as the previously described 'C' shaft equipment, will ultimately be put into service at the 'D' shaft. Initially, however, one winder only is to be installed, the equipment for which is in course of manufacture. Designed for skip and counterweight working, the output at this stage will correspond to 350 tons/hr based on the 1,674 ft (Hutton) level. But this winder will also serve the Busty level at 2,150 ft, operating at a maximum rope speed of 40 ft/sec.

Four $1\frac{3}{8}$ in dia locked-coil winding ropes will support a guillotine-door skip ($17\frac{1}{2}$ tons tare, 20 tons capacity) and a 27·5 ton counterweight. Complete equalisation of the winding ropes is to be obtained by the use of twin flat balance ropes. Six half-lock rope guides will be employed with arrestor arrangements, as for the 'C' shaft equipment.

The shaft, which will serve as upcast, will be surmounted by a 185 ft circular reinforced concrete tower. Fig. 11 shows a model of the tower and heapstead buildings.

Winder

Duplication of the 'C' shaft winder has formed the principal basis for design but advantage has been taken of subsequent developments, both electrical and mechanical. Multi-unit, high pressure hydraulic-spring brakes with parallel acting shoes replace the less versatile low-pressure unit. The winder main bearings have also been modified for pressure lubrication.

Following the pattern of earlier friction winders in No. 1 Area the lower deflector floor accommodates the emergency manual control station. The station, in the form of a control desk, incorporates a direct mechanically driven, precision miniature depth indicator, in addition to signalling, control and changeover equipment.

The motor-generator house and switchroom

The m-g house will ultimately accommodate the twin m-g sets, exciter sets and high-speed d.c. air circuit breakers, the associated control and h.t. switchboards being separately housed in an adjacent room. Changes in the winder control system have eliminated the pilot exciter and control exciter, and the exciter sets now incorporate a 400c/s alternator in addition to the constant-voltage exciter and generator exciter.

Remote control stations

The remote control stations, situated at the skip discharge and underground tippler positions, will each be equipped to control the twin winders and skip handling plant. Initially each console will include controls for a single equipment with a mimic diagram for the ultimate arrangement. The controls for the second winder will be incorporated in extension units.

Selection of semi-automatic or fully automatic control is to be in the hands of the banksman, who will also select the underground working level. Remote indication of depth, using Selsyn transmission, will be provided at the skip discharge station to facilitate inching under semi-automatic control.

Changeover arrangements will transfer the signalling facilities for the remote stations to the shaft side for emergency men-winding.

The control system

Control of the winders will again be on the closed-loop principle but making more use of static control equipment. The system is illustrated in block schematic form in Fig. 12 and can be sub-divided as follows :—

(i) Speed control.

(ii) Reference control.

(iii) Torque/current control.

(iv) Protection.

Speed control

The components in the speed control loop are the generator magnetic amplifier (GMA) generator exciter (GE), variable voltage generator (VVG), winder motor (M) and speed measuring pilot exciter (PE). The action of this type of system is such that the quantity to be controlled (output) is compared with an external and independent reference and the difference between the two quantities, known as the error, is used to cause the controlled quantity to approach equality with the reference.

Fig. 11—A model of 'D' shaft surface construction at Wearmouth colliery

Assuming initial steady-state conditions and a fixed reference, any output disturbance (e.g. load change) is reflected as a change in output, and so a change of error. Steady state conditions again obtain when the error and output have automatically adjusted themselves to regain equilibrium. The magnitude of the error change to balance the load disturbance is a function of the system gain (neglecting transient conditions) and, by adopting a high gain, as in the system under consideration, the winder motor speed may be considered substantially constant for a given reference over the range of winder load conditions.

Reference control

The attainment of a close relationship between

applied reference and winder motor speed transforms the problem of cyclic speed control to cyclic reference control, i.e. accurate control of the reference voltage with respect to time.

For this purpose an independent closed-loop system is employed, shown within the chain-dotted rectangle in Fig. 12. A single magnetic amplifier performs the function, the elements associated with which include a static limiting network and static differentiating circuit. The action of the system is in fact similar to that of the pilot and control exciters used in the 'C' shaft winder speed control system, the rotating amplifiers being replaced by a magnetic amplifier.

The input from the driver's faceplate potentiometer is compared with the reference control output and the difference is used as a correcting signal. This signal is applied to a limiting network which produces a substantially constant output for all correcting signals. The output of the network constitutes an accelerating signal and is compared with the actual rate-of-change of reference as measured by the differentiating circuit. Adjustment of the reference output at the pre-set rate-of-change is thus produced by the difference between the outputs of the limiting network and differentiating circuit.

Steady state reference obtains when the reference output becomes equal to the system input from the driver's lever, i.e. the correcting signal becomes zero. Under this condition the output is self sustained at this level by a positive feedback within the amplifier; this gives the reference control system the quality of an integrator.

Adjustment of the rate of change of reference, and hence winder motor speed, is readily carried out by modifying the circuit resistance to which the accelerating signal is applied.

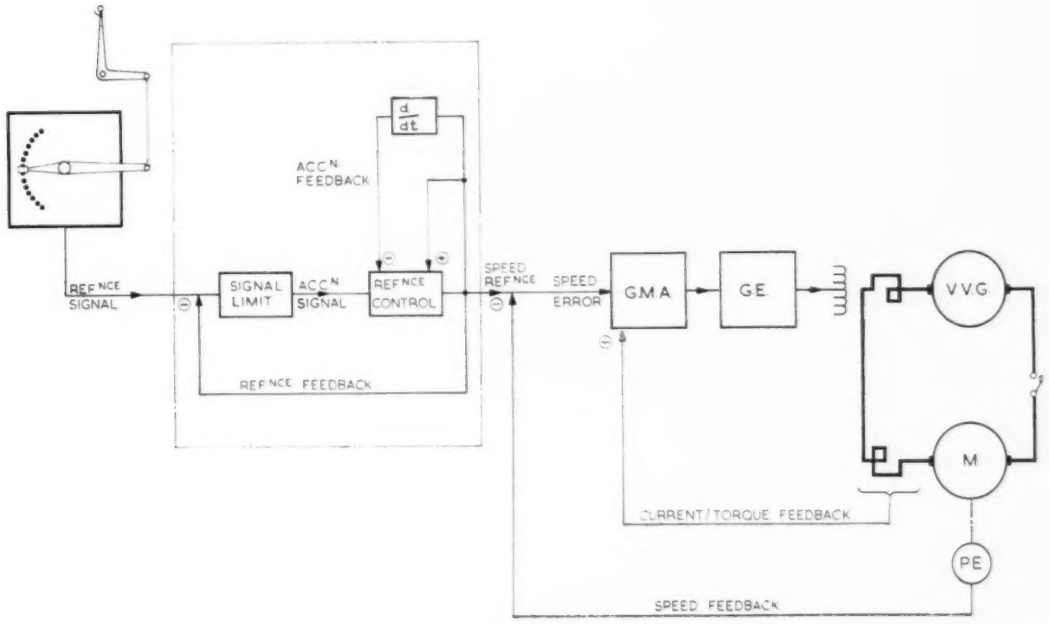

Fig. 12—Block diagram of 'D' shaft winder control system (stabilising circuits omitted)

Torque/current control

To facilitate winder motor torque build-up, to prevent the attainment of excessive armature

current at standstill, and for ' suiciding ', a current (torque) feedback is provided. This feature is similar in operation to that described in the ' C ' shaft control scheme.

Protection

A closed-loop control scheme readily lends itself to the introduction of protective features. Such a feature is provided by the torque/current control which is automatically modified, when the brakes are released, to impose a limit to the peak current of the winder motor. This limit is normally adjusted to operate at a current greater than that necessary to operate the protective relay, to prevent stalling of the motor at an undesirable current level below the relay setting.

Stabilising

In the interests of clarity, the block diagram, Fig. 12, has been confined to components which contribute directly to the achievement of the basic control requirements. It is necessary, however, to introduce additional feedback elements into the system to obtain a stable response to changes of input. These elements respond to rates of change within the system and eliminate oscillations.

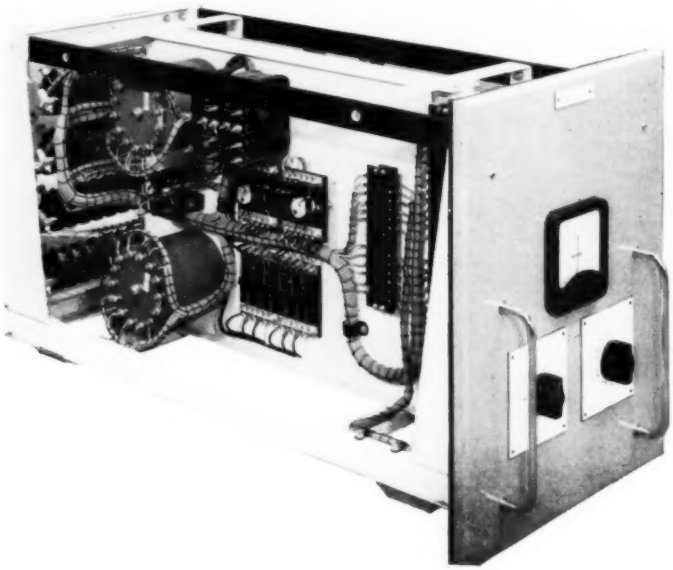

Fig. 13—Withdrawable chassis accommodating reference control unit

Operation

Selection of the mode of operation will be under the control of the banksman, the available forms being : manual control, from the tower ; semi-automatic control, from the skip discharge and underground tippler stations ; and automatic control, by which the winder is conveyance-initiated with supervision from the skip-discharge station.

Operation of the winder will be, in principle, as described for the ' C ' shaft equipment. Only as an emergency operation will winding be carried out under manual control, so means for remote manual control will not be provided.

The adoption of skips for intensive coal drawing involves alternative arrangements for conveyance loading and discharge. The loading pocket feeders at the underground levels and transfer conveyors at the surface are completely interlocked, so that the system readily lends itself to fully automatic operation.

EXPERIENCE GAINED on earlier semi-automatic friction winder installations was applied to advantage during commissioning of the ' C ' shaft equipment. The decision to take the auxiliary drive from the deflector sheave shaft had been previously justified, the rope creep and rate of wear of the friction material having been found to be less than on the driving sheave. Even a modest rate of wear on the driving sheave would affect the distance measuring equipment, particularly if a high number of sheave revolutions per wind are involved, and would have necessitated frequent re-setting of this equipment. Justification of the adoption and continued use of the equipment under semi-automatic control is realised by the attainment

of a consistent, practical working cycle coupled with increased safety and reduced operating costs. This in no way reflects upon the skill of the driver—a comparison of manual against automatic control, based solely on minimum cyclic time achieved is of course fallacious.

An allowance landing tolerance of datum minus two inches, necessary for satisfactory cage unloading without platforms, demands a high control accuracy if excessive creep time is to be avoided. The ability of the 'C' shaft scheme to meet the requirement has been established and subsequent development has been focused upon the adoption of improved techniques to minimise maintenance.

The pursuance of this principle is again evident in the scheme for the 'D' shaft, which will incorporate static magnetic amplifiers, requiring no maintenance. A further trend towards the simplification of fault location and servicing has also been taken in the adoption of withdrawable chassis equipped with comprehensive monitoring facilities for housing the static elements. Such a chassis, containing a complete reference control unit, is illustrated in Fig. 13.

Simultaneously, increased accuracy of control will be achieved ; this has been indicated initially by the results of simulation on one of the Company's analogue computers.

In retrospect, the trend of development at this colliery towards the winning of coal with ever increasing efficiency and safety is representative of the requirements of the industry. In the future, selective application of new techniques and the continuance of the close co-operation between user and manufacturer will accelerate the advance in productivity.

ACKNOWLEDGEMENT

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A.C/D.C. Welding Equipment: A New Range

by R. H. BOUGHTON, M.Inst.W., Manager, Welding Equipment Division

THE RATE OF development in welding accelerated during the late 1950s and is continuing to do so in the 1960s. The processes involved are already numerous and are being added to all the time. In consequence, it has been necessary to review the manufacture of welding equipment to provide satisfactory power sources for each process. These power sources split broadly into two categories: drooping characteristic and level characteristic. Level characteristic power sources are used in conjunction with welding processes using a fine wire fed rapidly through a gun or welding head, and such processes have an inherent current control which is determined by the pre-set open circuit voltage (normally in the order of 15V to 35V) and the wire feed speed. If the wire feed speed is increased the current also is increased. This type of mechanism is used in CO_2 welding, and a similar arrangement, using a.c. current, is applied to the electro-slag welding processes on which much development has been done in recent years.

The new range

Practically all other welding processes require a drooping characteristic power source of either a.c. or d.c. and it is to meet this requirement that the Company has developed the LWAD range of welding equipment, which is the first equipment of its type to be developed in the U.K. It gives an output of either a.c. or d.c. current, selected by the turn of a switch. This equipment is suitable for manual metal arc welding of all metals, carbon arc welding, certain stud welding processes, and gas-shielded processes using tungsten arc. Fig. 2 shows a welder at work with an LWAD 600 welding equipment, welding stainless steel with d.c. welding current.

In addition to the applications mentioned the LWAD equipment can be used very satisfactorily as a power pack for open-arc or submerged-arc

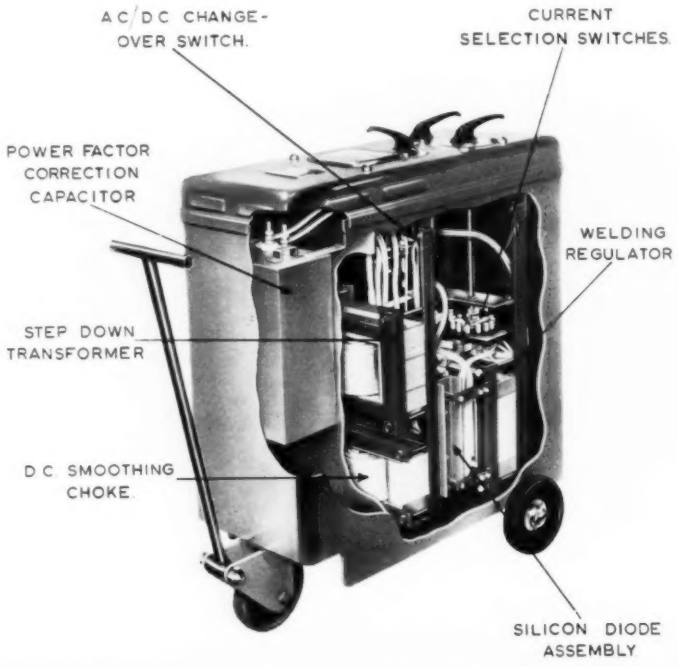
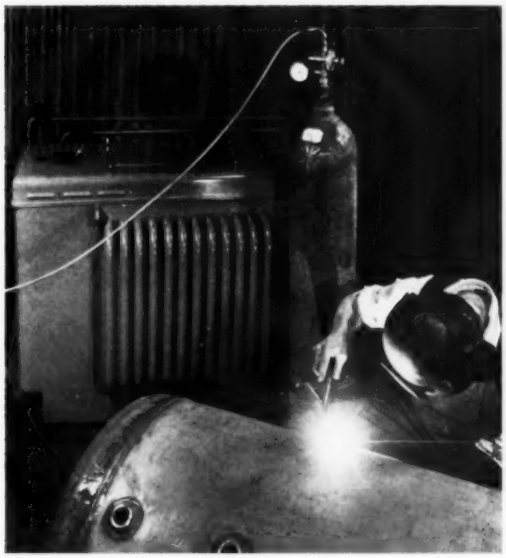


Fig. 1—Cut-away view of a 450A a.c/d.c. welding equipment



[photo: G. A. Harvey & Co.]

Fig. 2—An LWAD 600 equipment being used for argon arc welding of stainless steel at the Greenwich works of G. A. Harvey & Co. (London) Ltd.

automatic welding within the range of its capacity. It is also the ideal power source for the well-known metal-removing process, 'Arc air' gouging.

The versatility of the LWAD range of equipment is a very important feature where a wide range of products and processes have to be undertaken in a particular shop. Whereas it was previously necessary to have both a.c. welding transformer and d.c. motor-generator units, all the work can now be undertaken from a single equipment which is competitive in cost with a d.c. motor-generator of similar rating. The LWAD welding equipment is simple in construction, consisting essentially of a single-operator a.c. welding transformer and current regulator together with a bridge-connected silicon diode rectifier, d.c. smoothing choke, a.c/d.c. changeover switch, and an ancillary protective circuit to ensure that the silicon diodes are not subjected to transient over-potential conditions. The compactness of the silicon diodes allows the whole equipment to be housed in a conventional single-operator welding equipment tank ; this in turn has led to rationalisation of production, because practically all the components common to the single-operator transformer equipment range have proved suitable for incorporation in the LWAD range. Furthermore, the low losses of the silicon diodes on this duty compared with selenium have made it possible to use a tank of reasonable size. Had such a development been contemplated with selenium rectifiers at least twice the cooling surface would have been required, resulting in a cumbersome equipment.

In addition to its versatility this range is particularly suited for operation overseas, because the construction is simple. Also, having no wearing parts, little maintenance is required, whereas motor-generator welding equipments require constant attention to brushes and commutator, regular greasing, and periodic attention to current-control mechanisms. Furthermore, silicon diodes work satisfactorily at temperatures up to 190°C. In the LWAD range the silicon diodes are mounted at the bottom of a large tank of oil and consequently are capable of welding over long periods at a high duty cycle without risk of the diodes overheating, thereby eliminating any risk of premature failure of the diodes.

The LWAD range is made in three sizes, viz : 300A, 450A and 600A rating on the a.c. side, with d.c. ratings of 250A, 360A and 520A respectively.

Additional equipments

In addition to the range of standard equipments a further range of plant is now being manufactured for power packs for automatic welding, these being known as the LWAAD 750 and 1200. In principle these equipments are the same as the LWAD range but have a motor-operated moving core regulator for current control, as against the tapped reactor method used in the smaller equipments. This range of equipment has been developed for heavier current automatic welding and the power packs have been designed for parallel operation, thereby giving outputs of up to 2,400A when using two plants, this being sufficient for any known welding processes at the present time.

The Role of the H.R.C. Fuse in the Protection of Low and Medium Voltage Systems

by E. JACKS, M.I.E.E., Chief Engineer, Fusegear Division

Copies of this article, translated into Russian, were issued in connection with the British Trade Fair in Moscow last May.

THE HIGH RUPTURING CAPACITY (h.r.c.) fuse, as a method of obtaining reliable short circuit protection at high values of fault current, was pioneered in Great Britain. An appreciation of the influences which preceded its introduction is helpful in the understanding of the present day developments, which still continue at an undiminished rate.

Electrical engineers in Great Britain have been specially conscious of the need for efficient short circuit protection because of the way in which electrical systems have evolved here. The U.K. became highly industrialised at an earlier stage than most other countries, so that the Electrical Industry grew rapidly from its earliest days. Such growth in a country of relatively small geographical area resulted in heavy and closely connected distribution networks and heavy load concentrations. In due course, co-ordination and interconnection was adopted on a national scale, involving the standardisation of transmission and distribution voltages. The system chosen for low voltage* distribution was 415/240 V, three-phase, a voltage somewhat higher than that used in most European countries or on the American continent. The high load densities also influenced the size of transformers feeding low voltage systems. These tended to be large and, in some industrial and city areas, were often of 1 and 2 MVA capacity in single or multiple units.

**In Great Britain 415/240 V is officially classed as medium voltage, but the term low voltage is used in its general sense to include this voltage.*

Under these circumstances fault levels grew to magnitudes which were not experienced in countries where electrical loads were distributed over larger geographical areas. Thus, the duty imposed on short circuit protective gear increased at a rate which kept British engineers constantly aware of short circuit problems on their low voltage systems.

The progress required in the field of electrical protection was intensified as electricity increased in importance as a service in industry and commerce, but other factors also conditioned the attitude of British engineers towards these problems. Long experience of industrial conditions had given rise to early legislation in Great Britain concerning safety requirements. These were accentuated by a strong public desire and demand for high standards of safety which, before the end of the 19th century had become embodied in the British Factory Acts. British codes of practice and industrial relations have been largely evolved round the Factory Acts and the electrical industry has from its earliest days taken the initiative in maintaining the highest standards of safety.

GENERAL TRENDS OF DEVELOPMENT

1920/1930

In the early 1920's the position regarding fuse protection on supply systems became acute because of the rapidly increasing fault levels and because the then existing designs were proving no longer adequate for the duty imposed upon them. Up to that time many hundreds of ingenious ideas

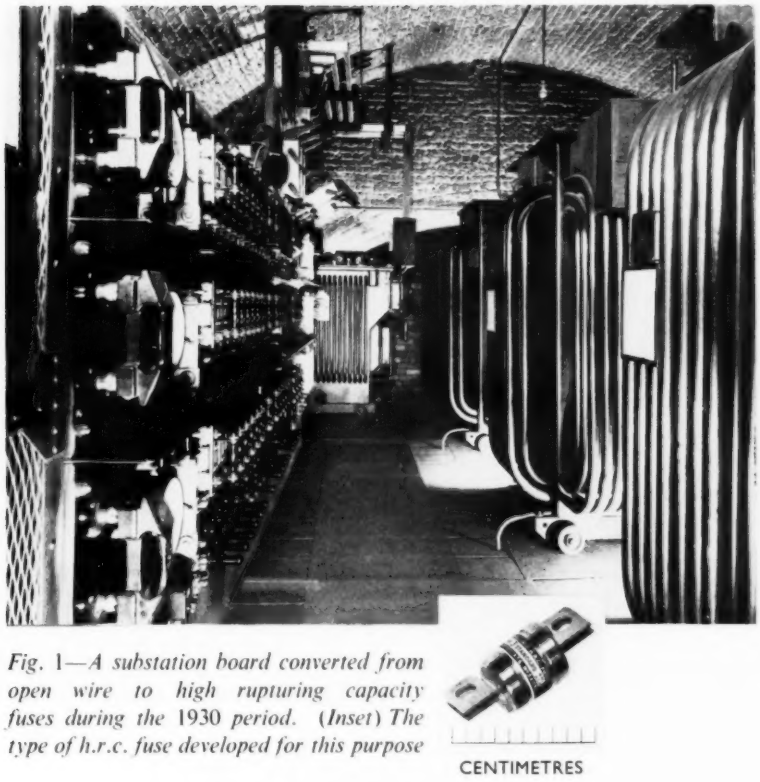


Fig. 1—A substation board converted from open wire to high rupturing capacity fuses during the 1930 period. (Inset) The type of h.r.c. fuse developed for this purpose

relating to fuse design had been patented in Great Britain. Most of these concerned the enclosure of or safe handling of wire or strip fuses mounted in various types of holders, including those of the simple cartridge type. The limitations of such fuses are well known and because of these limitations the h.r.c. fuse came into being as an urgent necessity in the more heavily developed areas of the country.

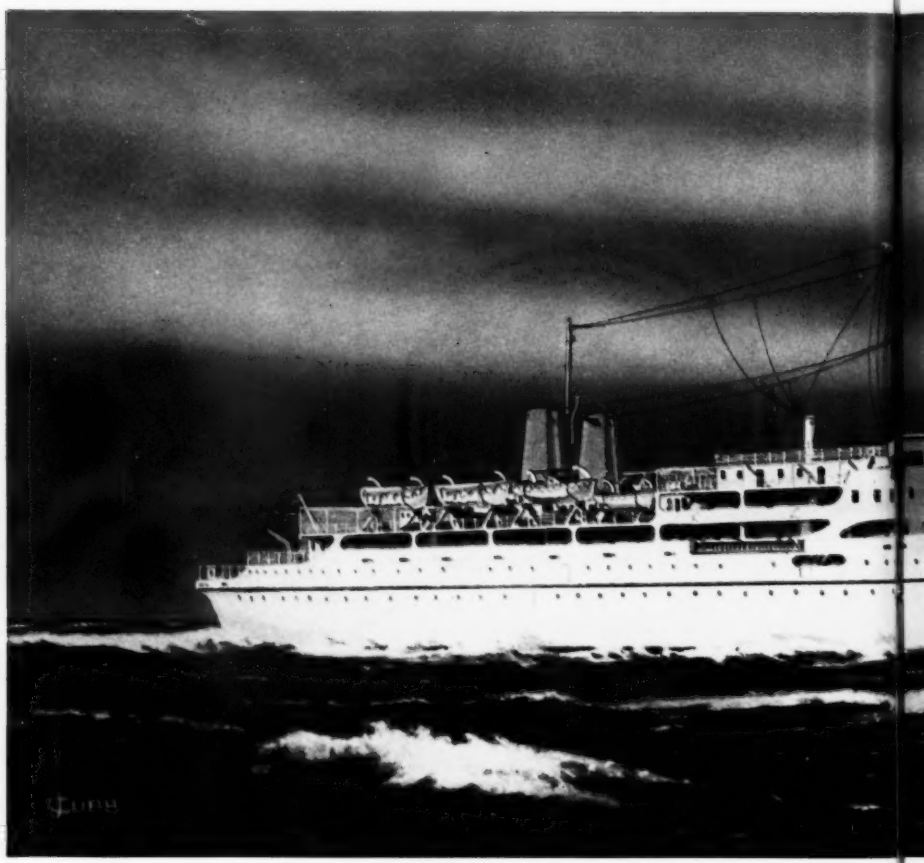
The term 'h.r.c. fuse,' meaning high rupturing capacity fuse, was used from the first to distinguish the new conception in fuses from other designs with inferior performance.

The English Electric Company were among the pioneers in this field and quickly attained prominence with designs which not only satisfied the immediate requirements of the time, but also laid the foundation for subsequent developments which have proved their value up to the present time.

The first demand for h.r.c. fuses was from public supply authorities who required them for the protection of low voltage networks. The nominal fault levels near to substations in highly developed areas was often in the region of 25 MVA at 415 volts (three-phase equivalent). Faults on such systems caused wire or strip fuses and inferior cartridge fuses to fail explosively, causing uncontrolled flashover which resulted in more damage than that caused by the fault itself. In the worst cases equipment adjacent to that handling the fault was also wrecked and valuable services were needlessly interrupted. Fire hazards and danger to personnel also became serious. Thus, the first demand upon the h.r.c. fuse was for effective and safe rupturing capacity.

Rupturing capacity was achieved both by research and intensive empirical development. The results were then proved by exhaustive practical tests on the very systems for which the fuses had been designed. The supply authorities co-operated in this work with the fuse manufacturers by offering their systems as testing grounds and by allowing heavy short circuits to be deliberately applied for testing purposes. Such co-operation viewed in retrospect illustrates most vividly the gravity and urgency with which the problem was viewed at that time.

The particular requirement of the supply industry was that the new fuses should be made to fit existing fuse mountings in order to facilitate the rapid conversion of existing networks. This requirement severely limited dimensions and it is worth noting that the current ratings of fuses required for such conversions were of the order



'English Electric' are to supply diesel-electric propulsio
depicted here, which is now under construction
Wireless Ltd. Propulsion equipment comprises fou 8
3000hp 800V 146r.p.m. main motors. Control will

Auxiliary power will be supplied by two 500kW ge
and two 500kW auxiliar di

...ropulsion equipment for the 6000s.hp cable laying ship, ...ion by Cammell Laird's of Birkenhead for Cable and ... fo... 8-cylinder main engines (type 8CSRLM) with two ...rol will be from several stations, including the bridge.

...k W... generators, tandem driven from the main engines, ...ilia... diesel-driven generators.

of 200 to 600 A. Fuse designers will appreciate that the difficulty of achieving rupturing capacity increases greatly with increase in current rating. It is to the credit of the earlier designers that they were able to produce the larger ratings with adequate rupturing capacity in such small dimensions even before the lower current ratings were considered. Fig. 1 shows a typical substation fuse distribution board which was converted in 1930.

1930/1940

After some years of experience of h.r.c. fuses in the supply industry advantages other than rupturing capacity began to become evident. The main advantages were accuracy and fidelity of characteristics and the ability to resist deterioration even under adverse service conditions. These advantages commended themselves to the user industries which were becoming economically dependent upon adequate electrical protection as electricity rapidly supplanted other forms of power. It was for these reasons that during the 1930s the h.r.c. fuse became established as a major short circuit protective device within industrial installations in Great Britain.

The main factor which influenced this adoption was undoubtedly that of discriminative protection which was made possible by the accuracy of characteristics inherent in the new fuse. Experience quickly showed that co-ordination between h.r.c. fuses themselves and with other devices was predictable to a high degree. The economics implied in these facts obviously had a direct significance in terms of industrial efficiency.

Another factor which commended the h.r.c. fuse to the industrial user was its ability to remain stable and reliable over long periods of duty. The importance of this is apparent when the duty of the fuse is considered in relation to industrial usage.

An event of considerable importance in 1938 was the inauguration in Great Britain of the Association of Short Circuit Testing Authorities. This is a voluntary co-operative organisation set up by electrical manufacturers to provide a number of high power testing stations and formulate rules for the independent certification of circuit

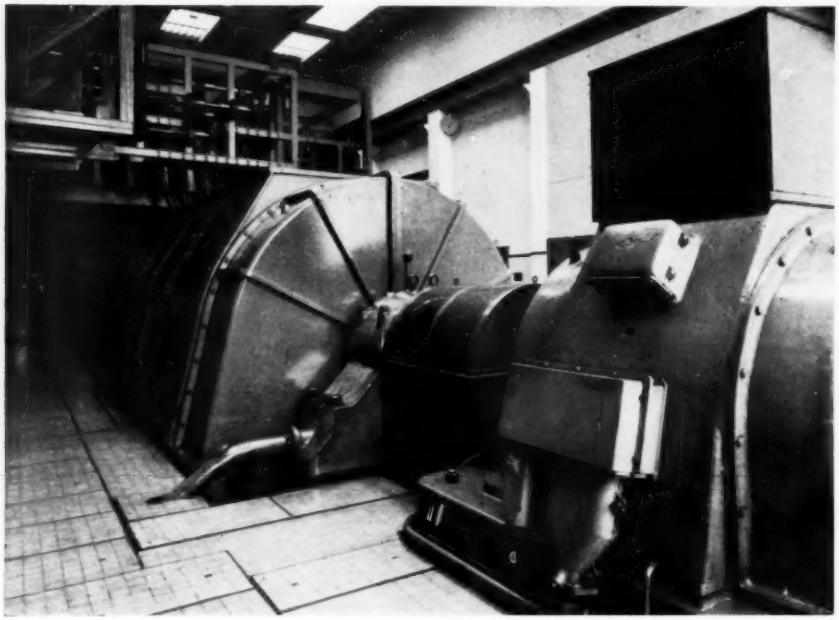


Fig. 2—One of several alternators installed at the Nelson High Power Laboratory, Stafford

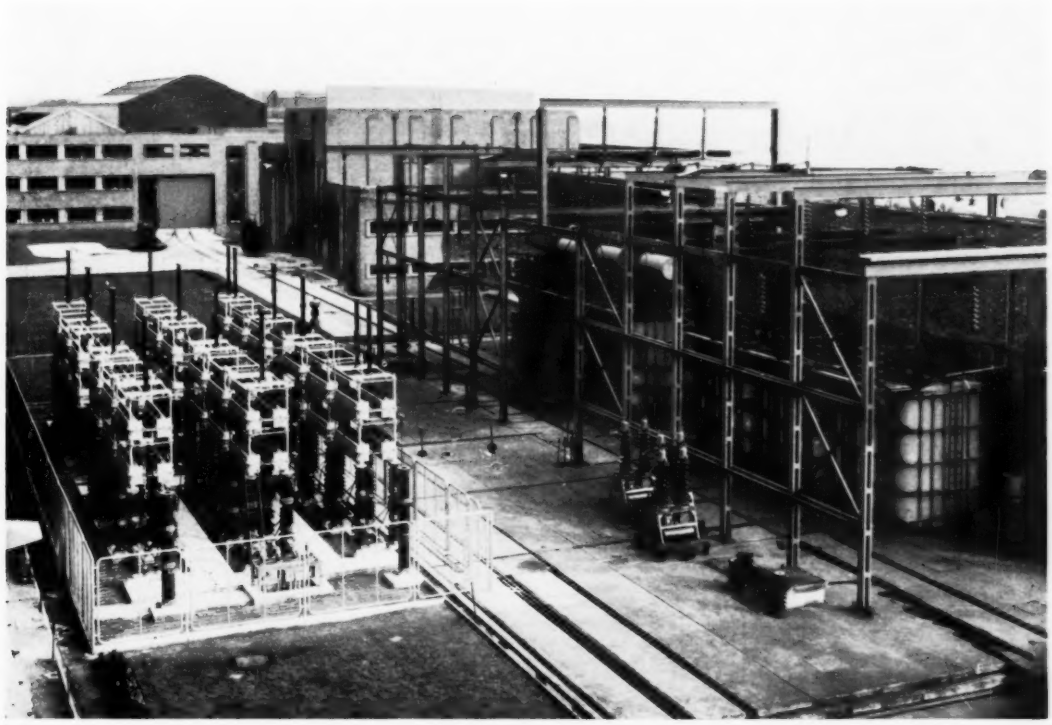


Fig. 3—Power transformers installed at the Nelson High Power Laboratory, Stafford

breakers, fuses and other short circuit interrupting devices. The Association is supervised by Government departments through the auspices of the National Physical Laboratory, by which means it is independent of individual manufacturers and serves the industry as a whole.

The emergence of testing facilities on such a large scale with adequate facilities for measurement and recording gave fuse designers an opportunity of proving their ideas and of pursuing further developments on a more scientific basis.

At this time, h.r.c. fuses were beginning to fulfil a useful role in marine practice. Several passenger ships having large generating capacities were found to have higher fault potentials than had been experienced previously. H.R.C. fuses were used to good effect and the opportunity this presented provided valuable experience on which present-day marine practice is based.

1940/1950

In the 1940s the use of fuses and the scope of their application was greatly widened and accelerated due to the impetus of the World War. Quite apart from the natural growth in usage due to industrial expansion, varied applications arose in other fields.

Up to this point fuses and fusegear had been mainly used on industrial installations for protecting and controlling the distributor cables or sub-circuits. Busbar zones were in general protected by oil circuit breakers. From 1940 onwards oil circuit breakers began to give way at an increasing rate to combinations of fuses and manually operated airbreak switches (Fig. 5).

Another symptom of that period was the extent to which h.r.c. fuses were used to back up existing circuit breakers to meet the increasing fault levels

which had occurred since the circuit breakers were first installed. This practice began as an expediency but quickly became recognised as an economic and logical arrangement for new equipment. Fuses required for both these applications tended to be larger in current rating than had hitherto been necessary and ratings up to 1200 A became fairly common.

rupturing capacity and the other factors mentioned, but an important new factor was the realisation of the ability of the h.r.c. fuse to withstand considerable shock and vibration without sustaining damage to itself. The same factor also accounted for the increased popularity of fuses in the sphere of traction, particularly on railways and underground tube systems.

Fig. 4—A control room at the Nelson High Power Laboratory, Stafford

At the other end of the scale the smaller current ratings also increased in demand even on sub-circuits where the fault levels were not such as to require high rupturing capacity. This development was merely an extension of the benefits to be derived from accurate characteristics, discrimination and non-deterioration. Another advantage in using h.r.c. fuses throughout an installation was that calculation of fault levels in various situations was no longer necessary. Small fuses situated close to the main busbars could be of the same type as those at the end of the remotest sub-circuit. Thus, mistakes due to incorrect choice of fuses were eliminated.

During this decade the application of h.r.c. fuses in seagoing ships increased dramatically. The main reasons for this were still associated with

Meanwhile, fault levels continued to rise in some spheres. It is a recognised tenet in electrical engineering that system fault levels should be kept as low as possible. Cases began to arise however where system sectionalisation became impracticable on the grounds of economy. For these cases h.r.c. fuses of still higher rupturing capacity were needed and duly produced. These practices were reflected in the current British Standards which prescribed categories of duty up to 35 MVA at 440 V for standard ranges of fuse-links. Special cases arose where 60 to 80 MVA capacities were needed and these also were met.

1950/1960

Industrial recovery following the World War brought vastly increased usage of electricity in

the early 1950s. The role of all protective gear intensified in importance. The effect of this on h.r.c. fuse development was to exploit its many advantages on a still more scientific basis. The ability of the h.r.c. fuse to limit short circuit current and thus to minimise the effect of short circuit stresses had long been recognised, but the emphasis up to that time had still been mainly upon rupturing capacity. The new circumstances meant that whereas in previous years engineers had been

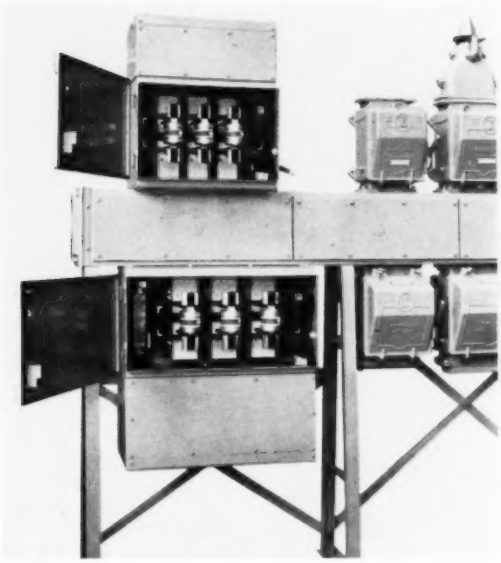


Fig. 5—A fuse switchboard incorporating fuses for protection of busbar zone

content if a protective device interrupted a faulty circuit without damaging itself, in 1950 they expected that it should also have the ability to minimise fault damage. The importance of this point of view was emphasised in many quarters and h.r.c. fuse designers were quick to exploit the new requirements. A considerable amount of work was done to explore and demonstrate the way in which short circuit energy could be limited to minimise fire risk, danger to personnel, or the time required to repair a damaged piece of equipment in order to restore the service.

Other associated problems were those concerned with operational safety to personnel. Closer consideration was given to the possibilities of fusegear equipment being closed on to faulty circuits by unskilled operators. It was demonstrated that danger in such circumstances can be reduced to negligible proportions and the effectiveness of h.r.c. fuses when properly applied in this respect has now been amply proved by experience.

Fault energy limitation is also significant in relation to industrial automation and to the tendency towards large integrated continuous process plants. The effect of electrical faults on expensive capital plants can be economically serious. Any measures taken to improve the effectiveness of protection to prevent prolonged stoppages is obviously worthwhile.

One of the most exciting challenges to the fuse designer in recent times has been that of protecting semi-conductor power rectifiers. The problem is difficult because of the extremely low thermal capacity of the rectifier cells. It has been stated that the ultimate output of these devices may well be determined by the effectiveness of the protective devices available. High speed h.r.c. fuses are now in regular and successful service for this duty, which has presented new problems entirely unlike any which have previously been encountered in fuse technology.

A further example of the increasing scope of h.r.c. fuses is that of the advances which have been made in the protection of aircraft systems. As in all other fields of electrical activity, generating capacities and therefore fault levels are increasing in aircraft at a rapid rate. System voltages in aircraft are also tending to increase and are not now dissimilar to those met with in industrial practice. Up to the present time it has been the custom to use conventional h.r.c. fuses in those aircraft circuits which required them. In 1960 The English Electric Company, after consultation with aircraft designers to properly ascertain their requirements, introduced a full range of h.r.c. fuse-links specially designed for aircraft use.

The art of h.r.c. fuse design has now progressed to such a stage that rupturing capacity in itself at low and medium voltages is no longer a serious problem. Rupturing capacities up to 200 kA r.m.s. (symmetrical) at 600 V are specified in some quarters and fuses are now available for these values. In this respect Great Britain is in a much

better position than most other countries because of the progress which has been made in testing station development, under the aegis of the Association of Short Circuit Authorities, and by the enterprise of certain companies.

FUNDAMENTAL PARAMETERS OF PERFORMANCE

The basic technology of fuse design and performance is well known and has been discussed in published literature elsewhere. It is useful however, to reiterate the principles and to discuss the more fundamental aspects of performance, in order to better understand the prevailing points of view as regards h.r.c. fuse protection in Great Britain.

Rupturing capacity

Rupturing capacity in an h.r.c. fuse stems from the fact that the fuse limits the short circuit energy to a value which is within its own capabilities to absorb. The basis of fuse design is to predetermine the energy which will be released and to provide an arrangement of cartridge and filler which will contain this energy. Such information is usually interpolated from empirical data. The physical size of an h.r.c. fuse is roughly proportional to the nominal current rating and is largely independent of rupturing capacity. Hence, the smallest fuses can, if properly designed, have very high rupturing capacities.

The amount of energy required to melt a fuse is sensibly constant for very short operating or blowing times. Thus, however high the available or prospective short circuit current may be the fuse will limit the actual current to a definite value, depending upon the rate of rise of the current. The rate of rise is maximum at the highest prospective current and maximum asymmetry. Hence a limiting value can be defined which is associated with the severest conditions under which the fuse is intended to be rated. In British terminology this current is known as the cut-off current.

Electromagnetic stress within the fuse itself and also within the equipment it protects is proportional to i_c^2 (where i_c is the cut-off current).

Whenever fault current flows in a circuit inductive energy is stored and must be dissipated in the fuse or in the fault arc. (The circuit I^2r loss is usually negligible.) In the case of a solid fault all the energy is released in the fuse. Thus when the fuse element melts arcing begins and releases the inductive energy. At the same time the system recovery voltage also attempts to sustain the arc. The dissipation of inductive energy in a fuse gives rise to a voltage $(L\frac{di}{dt})$ across the arc. This is a function of fuse design inasmuch as the rate at which the arc is created and quenched is controllable. In the later stages of arcing the success of the fuse depends upon the rate of rise of dielectric strength being greater than the rate of rise of recovery voltage.

The pre-arcing or melting energy is proportional to $\int i^2 dt$ up to the time the fuse begins to arc. Likewise, the arcing energy is proportional to $\int i^2 dt$ during the arcing time. These terms are rationalised for convenience to I^2t where I is the r.m.s. value of i over the operating time of the fuse. I^2t also represents the thermal stress within the fuse and the circuit protected.

Rupturing capacity depends on keeping the total I^2t to a value which the fuse can physically withstand under all conditions of fault. For a given fuse element or arrangement of elements, the physical strength of the containing tube and its end caps must be sufficient to contain both the dynamic and thermal stresses created. The elements must also be so proportioned and disposed within the cartridge as to run cool on normal loads, and to be able to withstand transient overcurrents without damage. Designing to achieve this involves the control of the mass of the element which is consumed during arcing. The number and disposition of the elements is also a factor.

It is desirable to keep the pre-arcing I^2t to a low value but not necessarily to a minimum, as this must be balanced against the ability of the fuse to carry loads without overheating. It also must be chosen to provide proper discrimination with other fuses.

Arcing I^2t depends first upon the value of pre-arcing I^2t and then the means provided for quenching the arc. The arc is controlled by the shape and dimensions of the elements and also by the cooling media. Again the optimum value of the arcing

I^2t must not be a minimum because of the considerations of arc voltage. Arc voltage must not be so high as to overstress the system insulation, bearing in mind that system insulation levels tend to reduce in service with the passage of time. The fuse operation should provide an even decrement of the current during the arcing period, so as to give an arc voltage well within the system insulation flash test value.

Another most important aspect of rupturing capacity which is often overlooked is that it determines the optimum accuracy required in manufacture. Thus, the accuracy required to give rupturing capacity ensures consistency and fidelity in other characteristics. This is one justification for using h.r.c. fuses in cases where fault levels are not particularly onerous.

Non-deterioration

Non-deterioration is a function of both fundamental design and control in manufacture. All protective equipment performs a passive role during most of its life and assumes an active role only when a fault occurs. This, on a well-found system, happens rarely. It is therefore necessary to know how a protective device may change its characteristics with the passage of time. With this knowledge it is possible to decide how often it must be changed or recalibrated to remain completely safe and effective. These questions have a special significance in the case of h.r.c. fuses because engineers do not expect to have to change them, even after many years of service. This is a natural attitude which arises because the fuse is a purely static device. Its elements cannot be inspected and it is practically incapable of being recalibrated once it has left the manufacturer's factory. The ideal fuses must therefore be designed in such a way as to prevent deterioration and so maintain safe characteristics for a long period. Account must also be taken of the possibility that the fuse may be subject to transient overcurrents of various kinds and to other hazards, even including incorrect usage. The property of non-deterioration must be regarded as one of the essential factors in the effectiveness of fuse protection.

Fuses taken from service after twenty-five years of continuous duty have proved that non-deterioration is an accomplished fact. Such duty has included continuous and cyclic loading, short time overloading, high transient overcurrents, wide variations of atmospheric and ambient conditions, industrial contaminations and the hazards of handling and routine maintenance.

The features in design which determine non-deterioration are, broadly speaking, the correct choice of materials for chemical compatibility ; correct heat transfer by proper proportioning of components ; avoidance of dry joints and connections ; proper protection of all exposed parts to withstand atmospheric pollution. To give effect to such designs involves scrupulous cleanliness and quality control in manufacture.

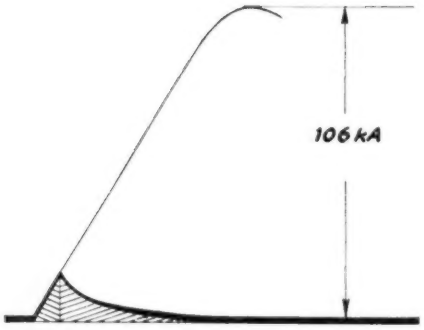
Non-deterioration also depends upon recognition of an optimum current rating and proper ratio between this and minimum fusing current. It presupposes that the fuse will not be made to carry currents greatly in excess of its nominal rating for prolonged periods in service. This does not necessarily mean that the ratio (or fusing factor) between current rating and minimum fusing current need be unduly high.

The art of fuse design therefore centres around the correct choice of parameters to give current rating, rupturing capacity and non-deterioration in adequate proportions.

As a corollary to non-deterioration the design should be such as to ensure that the fuse operates safely at all values of overcurrent below minimum fusing current. Such operation may take place after the fuse has been overloaded for very long times, perhaps after many weeks.

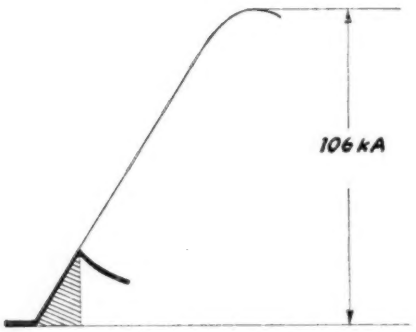
Discrimination

Discrimination under heavy fault conditions occurs between h.r.c. fuses when the total I^2t admitted through the smaller of two fuses connected in series is less than the melting of pre-arcing I^2t of the larger fuse. As fuses are usually identified by their nominal current ratings, it is necessary to know the appropriate I^2t values of each. In the interest of simplicity it is normal to consider only the value of total I^2t which results under the severest arc energy conditions. If discrimination can be obtained on the basis of such values then it will be obtained under all conditions which can occur in service. Fig. 6 shows oscillograms from actual discrimination tests and illustrates the principles involved.



(*a*) 160 *A fuse tested at rated rupturing capacity. Total* $\int i^2dt = 333 \times 10^3$ A^2sec

(*b*) 160 *A fuse tested to produce maximum arc energy. Total* $\int i^2dt = 430 \times 10^3$ A^2sec



(*c*) 300 *A fuse. Pre-arcing* $\int i^2dt = 460 \times 10^3$ A^2sec

Fig. 6—160 *A fuse in series with* 300 *A fuse gives discrimination. Total* $\int i^2dt$ *of minor fuse is less than pre-arcing* $\int i^2dt$ *of major fuse. Power factor is* 0·15

The factors inherent in fuse design which affect discrimination are : the ratio of pre-arcing to arcing I^2t ; the magnitude of the fault current in relation to the cut-off or limitation of current ; and the accuracy of the fuse under all conditions. Other factors external to the fuse itself, such as the layout of the system, can also influence discrimination and must be taken fully into account although the calculations in respect of these need not be critical.

H.R.C. fuses will give discrimination to a degree which is well within the requirements of normal service. Their characteristics can be predetermined and declared with an accuracy which compares favourably with induction relays and other similar devices.

BRITISH STANDARDS

British Standards exist for all types of fuses. Low and medium voltage h.r.c. fuses are governed by B.S.88 which is the principal specification on which other Standards and specifications have been modelled. This standard concentrates on performance and categories of duty rather than dimensions. These are recommended but are not mandatory, a policy which has proved to be wise inasmuch as it has allowed full scope for development without the restrictions which are unavoidable if dimensions are made mandatory at too early a stage. Design has in fact crystallised due to the lead given by certain manufacturers. Thus standardisation has occurred naturally by mutual consent of the users.

B.S.88 lays down current and voltage ratings ; categories of short circuit duty ; fusing factors ; limits of temperature rise ; methods of presenting time/current characteristics ; and conditions of usage. It also prescribes tests for the determination of all these on the basis of the most onerous conditions likely to be encountered in service. British Standards are constantly reviewed and amended as necessary to keep them up-to-date. B.S.88 is no exception and is currently being revised.

Proving tests and certification

It is usual for a manufacturer of h.r.c. fuses to present to the user proof that the fuses sold comply in all respects with the British Standard. In

addition he issues such data as the user may need to enable him to supply the fuse to maximum effect.

Proof of compliance of the fuse with the requisite Standard is usually in the form of Test certificates, which are records of type tests carried out under prescribed conditions. A typical example of a test certificate proving short circuit performance is the 'Certificate of Short Circuit Rating' issued by the Association of Short Circuit Testing Authorities. This Association will test fuses only if they are designed in accordance with the relevant British Standard and comply fully with the criteria of proof laid down. The short circuit test is performed at an authorised testing station under the supervision of an observer appointed by a Government-sponsored laboratory.

Fig. 7 shows a typical test oscillogram which indicates the method of test and the conventional technical terms in fuse technology. It will be seen that the prospective current, power factor, closing angle (point on voltage wave at which circuit is closed), applied voltage, limits of arc voltage, and insulation of blown fuse are all prescribed.

The maximum arc energy within a fuse during short circuit operation does not necessarily occur at the maximum prospective current for which the fuse is rated. B.S.88 provides for tests which produce the maximum arc energy condition in addition to tests at the higher prospective current.

Other test reports are issued by the fuse manufacturer in respect of temperature rise at full load.

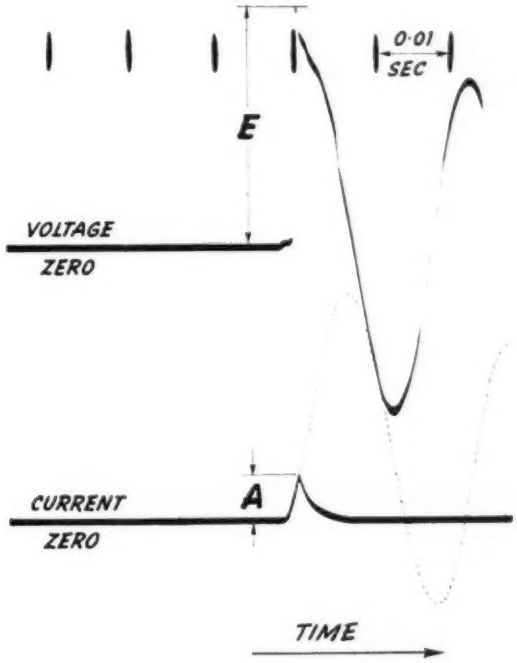


Fig. 7—An oscillogram of a test on an 'English Electric' fuse of 200 A 440 V rating

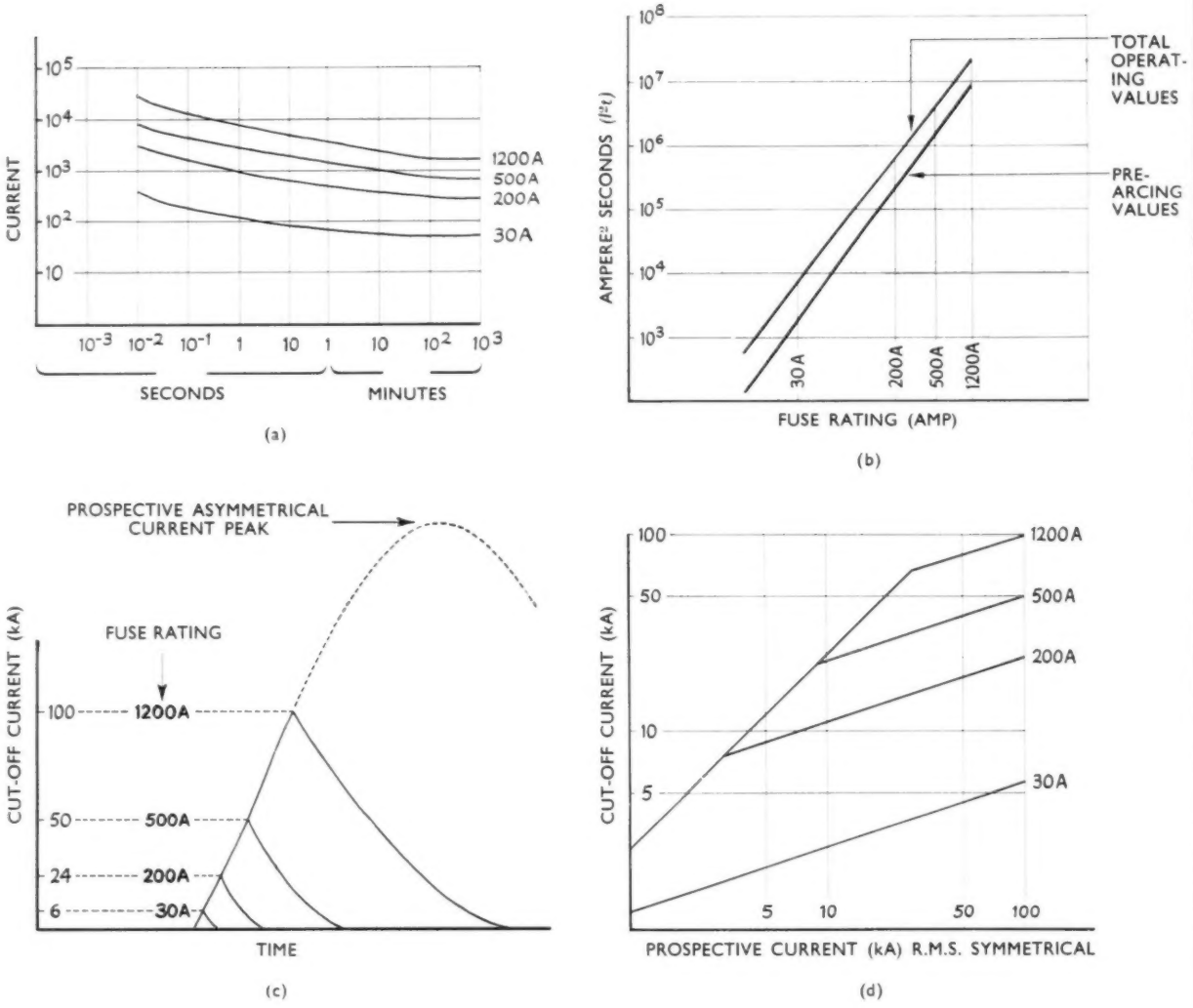


Fig. 8—Presentation of typical fuse data :—(a) Time/current characteristics (b) I^2t characteristics (c) Mode of operation (d) Current limitation

minimum fusing current, fusing factor, insulation resistance, and time/current characteristics.

Fuse data

Fig. 8a shows time/current characteristics for a typical range of h.r.c. fuses. The prospective current is plotted against the pre-arcing time. The curves do not extend for times shorter than 0.01 seconds because at times below this the fuse begins to exhibit cut-off and a different relationship applies.

A direct way of presenting data in respect of the high prospective currents is to declare the I^2t values. The pre-arcing I^2t of a particular fuse is reasonably constant. The arcing I^2t varies with the circuit constants, but if the value is taken from

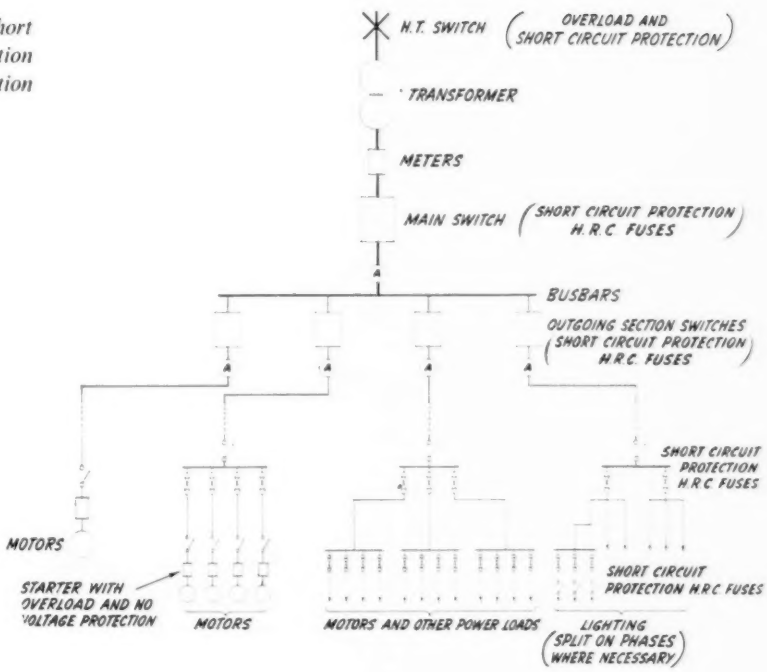


Fig. 9—Relative positions of short circuit and over-load protection in a typical industrial installation

the tests which produce the maximum arc energy this is a limiting value which will provide for safety under all circumstances.

Fig. 8b shows I^2t values for a range of fuses, plotted in a convenient form for assessing discrimination as well as giving total values for use in relation to circuit protection. Figs. 8c and 8d show other data normally issued in respect of fuse application.

APPLICATIONS OF H.R.C. FUSES

The applications of h.r.c. fuses are numerous and involve the employment of the principles of fuse design in varying degrees. For general industrial use the parameters are rationalised to give the widest scope of application. For special duties the parameters are defined to close limits.

The following examples are chosen to give a general picture of the whole field of application but it would be impossible in the space available to give more than an outline sketch of the subject.

Protection of industrial distribution systems

The majority of h.r.c. fuses are used in industrial installations. In these a

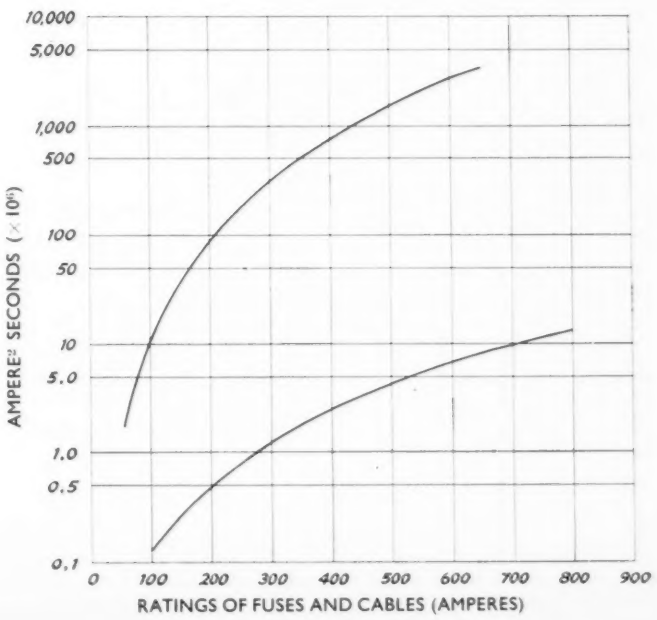
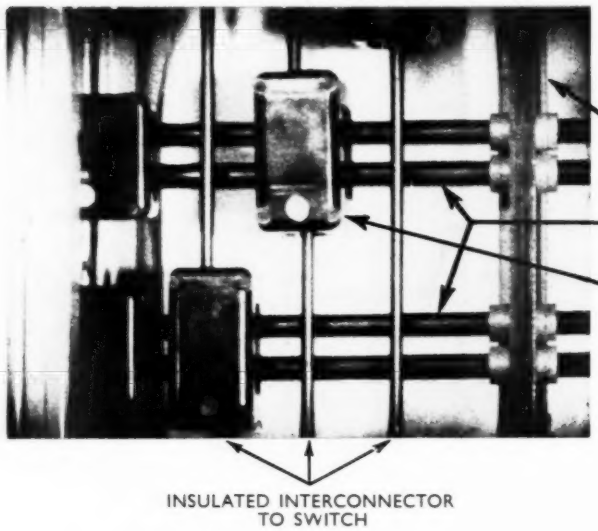


Fig. 10—Short circuit protection of cables. Upper curve: cable withstand. Lower curve: fuse let-through

distinction is made between short circuit faults which are electrical in nature and overloads which may arise from other exigencies. Short circuit protection is required primarily at all positions in a system. Overload protection is primarily required at the point of consumption to protect the consuming device, as indicated in Fig. 9.

H.R.C. fuses in the first place are for short circuit protection but embody a sufficient measure of overload protection to suffice for busbar zones, distributor cables and other conductors. Overload protection additional to the fuse is required to protect motors and other machines. Control of the distributors can be achieved by manual air-break switches, normally of the ' on load ' type and incorporating fuses.

The short circuit capacity of cables, contactor gear, and busbars may be related to the total I^2t admitted by the fuse protecting them. This relationship normally needs to be assessed from type tests because although the I^2t values of the fuses are readily available the short circuit withstand of other equipment is not so easily obtainable.



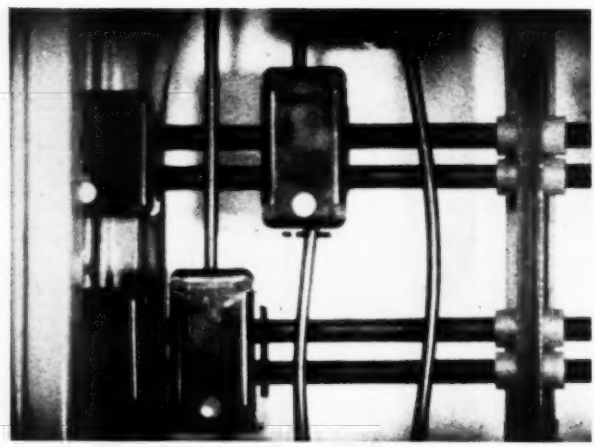


Fig. 11—Photographs from a high speed cine film, (1,000 ft/sec) showing conditions before (above) and after (below) a test on a 60 A interconnector protected by a 1,200 A fuse

Cables

It has been found that the I^2t admitted by a well designed fuse is so small compared to the withstand of the equipment it protects that it is only in marginal cases that accurate data is necessary for such equipment. This is easily illustrated by considering the short circuit withstand of cables in relation to fuses.

Fig. 10 shows the thermal withstand of cables in terms of I^2t compared with the I^2t admitted by fuses of the same current rating. The protective margin is so wide that it is possible to say that the short circuit withstand of the cables may be disregarded completely on a system protected by h.r.c. fuses of this type.

Busbars

The same sort of relationship also applies to busbar structures except that

in this case other factors emerge. Take for example a busbar of 1,000 A rating from which are fed airbreak switches of 100 A rating. The interconnection between the busbar and the switch will normally be of the same rating as the switch but will be protected by the device which protects the busbar. If this device is a 1,000 A h.r.c. fuse it can be easily demonstrated that the maximum I^2t which will be admitted by the fuse when a fault occurs in the switch will be well within the withstand of the 100 A conductors. These statements apply both to the electromagnetic stresses and to the thermal stresses. Fig. 11 shows the results of a test in which a 1,200 A fuse was blown when in series with such a conductor of 60 A rating. The values were exaggerated to show visible effects but it will be noted that although the conductor is distorted it is still capable of continuing in service at least until such time as it is convenient to replace it.

Fig. 12—A combination fuse switchboard for heavy industrial duty

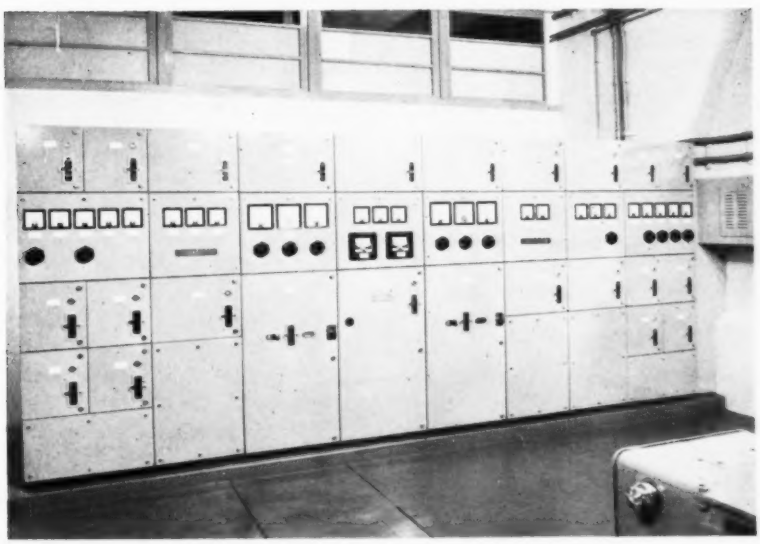


Fig. 13—A 'Superform' fuse switchboard for industrial duty in cleaner situations than those envisaged for the switchboard shown in Fig. 12

Fig. 12 and 13 show designs of fuse switchboards in which these principles are incorporated.

Contactor gear

The back-up protection of motor control contactors introduces other factors. The vulnerable items are the contacts which, unlike static conductors, are liable to movement under stress and are subject to much

SUMMARY OF THREE-PHASE SHORT CIRCUIT TESTS ON MOTOR CONTACTORS RATED FOR MOTORS OF 7·5 HP, 25 HP, 50 HP, AND 100 HP AT 600 VOLTS.

Unit	Duty	46kA			66kA			80kA		
		Average prospective current (kA)	Maximum peak (kA)	Average recovery voltage (V)	Average prospective current (kA)	Maximum peak (kA)	Average recovery voltage (V)	Average prospective current (kA)	Maximum peak (kA)	Average recovery voltage (V)
7·5 hp	TC	47·9	3·88	567	68·5	4·63	571	79·8	5·6	570
	M	46·7	3·38	576	66·4	4·63	585	80·3	5·71	583
25 hp	TC	47·8	9·62	570	68·5	10·3	570	79·7	10·2	564
	M	46·5	9·7	570	66·4	11·26	585	80·7	11·2	583
50 hp	TC	47·9	17·3	566	69·1	18·7	572	80·4	19·8	568
	M	47·0	16·2	575	66·6	18·5	585	81·2	19·5	588
100 hp	TC	47·9	22·8	571	68·3	25·8	566	80·6	27·1	572
	M	47·6	22·8	577	66·3	25·5	585	81·8	28·6	594

TC—Through fault with contactor closed
M —Making or closing contactor on to fault

higher current densities at the point of contact. Furthermore, they are liable to be 'closed' on to fault as well as to withstand 'through' fault currents. The fuses chosen for back-up protection must be co-ordinated in such a way as to allow the contactor to operate at all values of overcurrent within its own capacity. They must also be able to carry the transient over-currents during motor starting without deterioration. Thus the current rating of the fuse may be twice or three times the rating of the contactor.

Most British manufacturers of good quality control gear have carried out full scale tests at 25 to 35 MVA on their combinations of h.r.c. fuses and contactors. The results show that the h.r.c. fuse limits I^2t to values well within the withstand of all reputable designs of contactor. Short circuit protection is no longer a problem in this field, as is clearly demonstrated in Fig. 14.

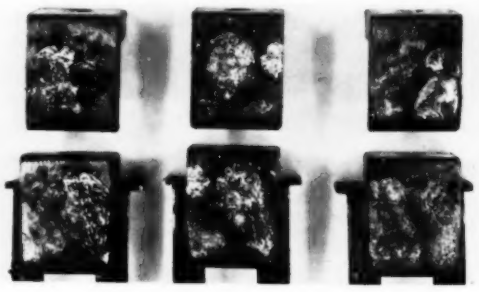


Fig. 14—Contacts of 100 hp contactor after the test tabulated above

Earth faults

Industrial systems in Great Britain are almost invariably three-phase 415/240 V with earthed neutral. The largest majority rely on h.r.c. fuses for system protection, including earth fault protection. This raises particular problems because the fuse ratings are in general larger than the cable ratings and have an average fusing factor (i.e. ratio between current rating and minimum fusing current) of 1·6. Under these circumstances earth fault protection depends entirely upon the effectiveness of the earth return path to the star point of the transformer. That is to say that the earth path impedance must be low enough to allow sufficient current to flow to blow the fuse quickly in the event of an earth fault. There is no difficulty in satisfying these conditions in the majority of industrial installations. The h.r.c. fuse provides a reliable method of earth fault protection which has all the advantages of simplicity and does not require specialised maintenance.

Low magnitude faults

Consideration of earth faults brings into focus the possibility of faults of low magnitude. The limitation of fault energy by an h.r.c. fuse is

applicable only on those faults which are of sufficient magnitude to cause the fuse to 'cut off'. At lower currents the time taken for the fuse to blow is in inverse proportion to the current. It is necessary to consider whether in the event of a low magnitude fault the fuse will blow before the system sustains damage.

As a general rule satisfactory protection can be obtained as exemplified in Fig. 15. In practice the possibility of a low magnitude fault (as distinct from an overload) occurring in this context is slight because electrical faults in cables usually develop quickly into high magnitude faults unless the cable impedance itself is too high. The fuse then deals rapidly with the developed fault and gives complete protection. If the cable impedance is too high this is an unusual condition and must be specially catered for.

Fig. 16 shows a typical design of distribution fuseboard incorporating fuses of ratings which are commonly involved in such problems.

Semi-conductor rectifier protection

The outstanding characteristic of semiconductor rectifier diodes is their large output and relatively small size. This makes them inherently difficult to protect because their low mass involves low thermal capacity and low thermal inertia. They are therefore susceptible to damage from over-currents even for very short times.

The only device that will respond to fault currents quickly enough to afford protection is the h.r.c. fuse, but this must be a specially developed type to match the characteristics of the semiconductor cells. A further complication is that

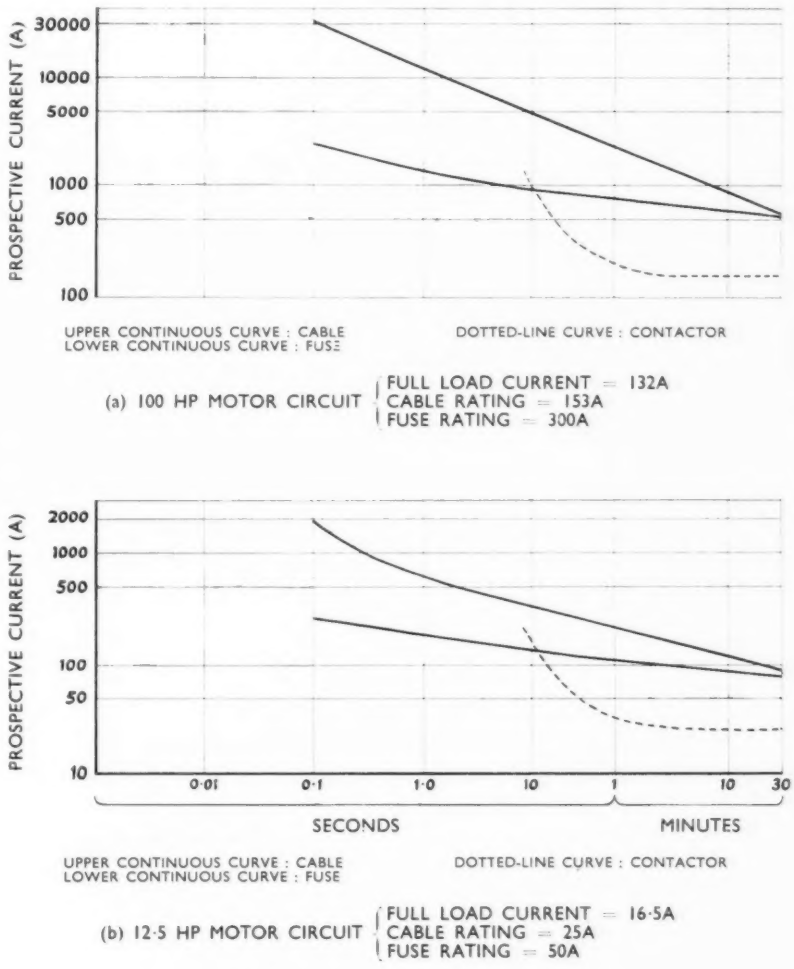


Fig. 15—Thermal protection of cables under moderate fault conditions. The cable curves indicate the 'no-damage' limit. The fuses afford protection, independently of the contactor, for overcurrents similar to those due to stalled rotor conditions

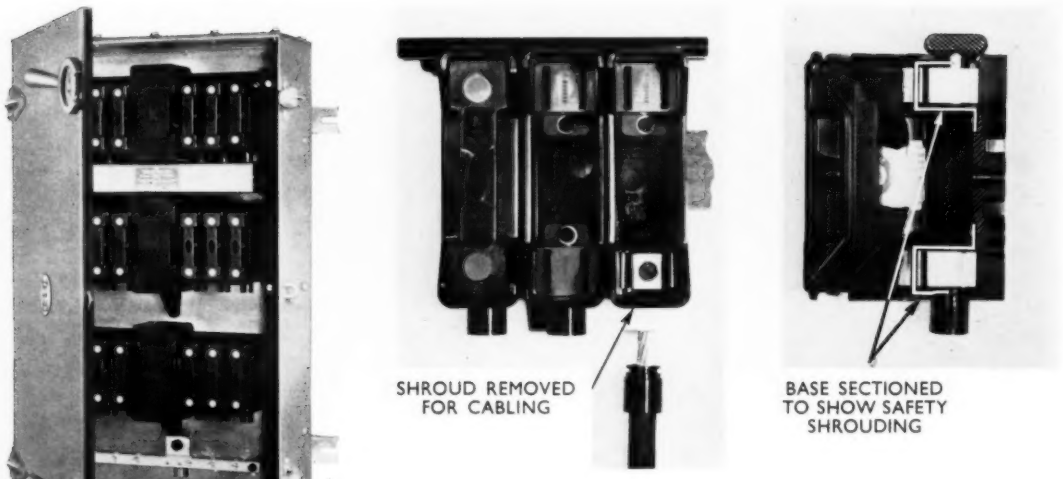


Fig. 16—An 'English Electric' Red Spot h.r.c. distribution board. The close-up views of fuse carriers and bases illustrate the operational safety features

these have a limited withstand against over-voltages. To be suitable for protection, a fuse must not generate arc voltage during fault operation because this would break down the reverse voltage withstand of the cell.

Fig. 17 shows the I^2t values, under given fault

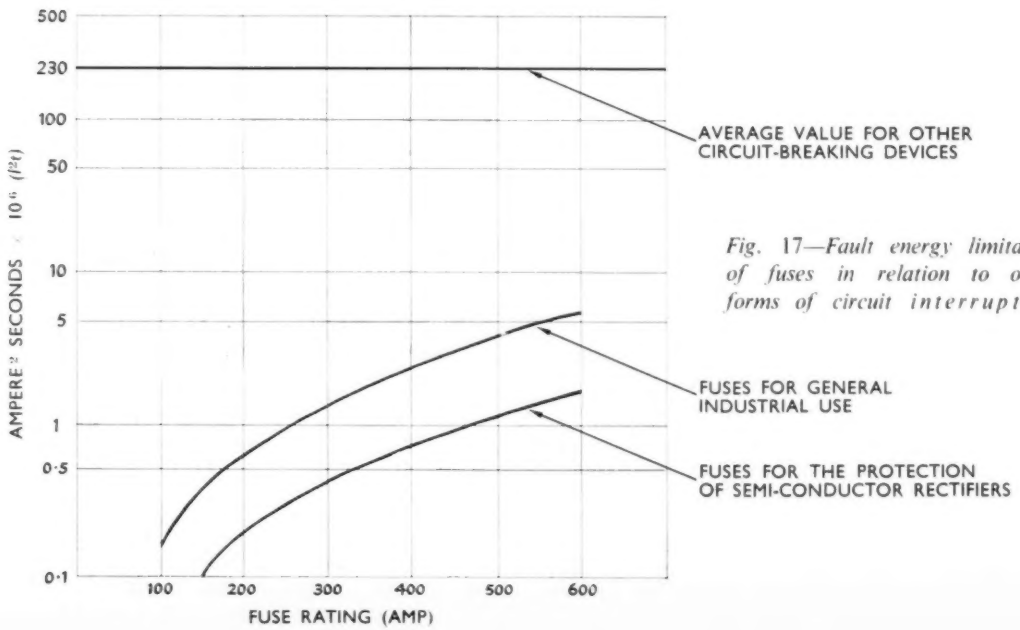
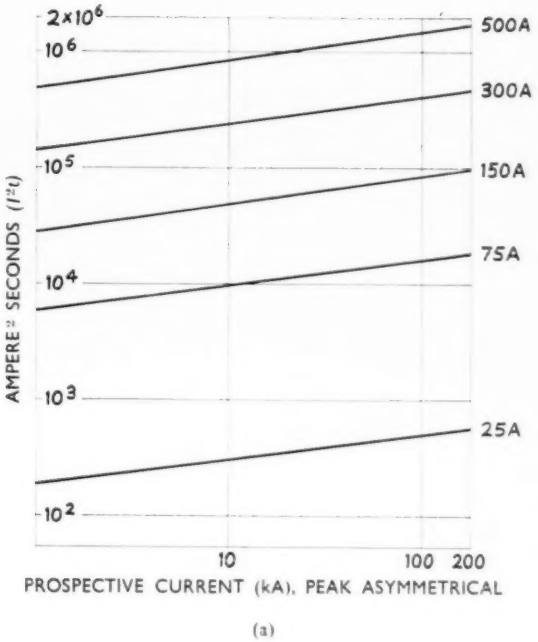
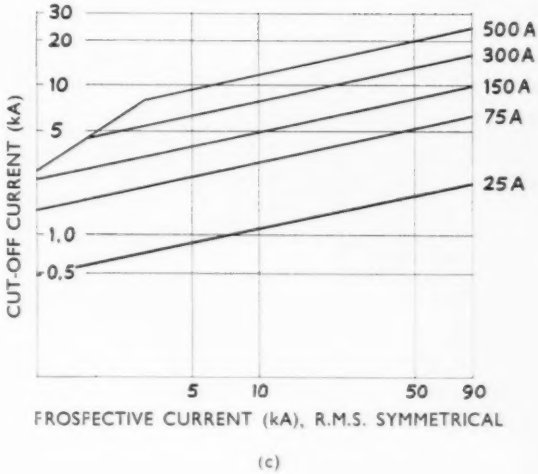


Fig. 17—Fault energy limitation of fuses in relation to other forms of circuit interruption



(a)



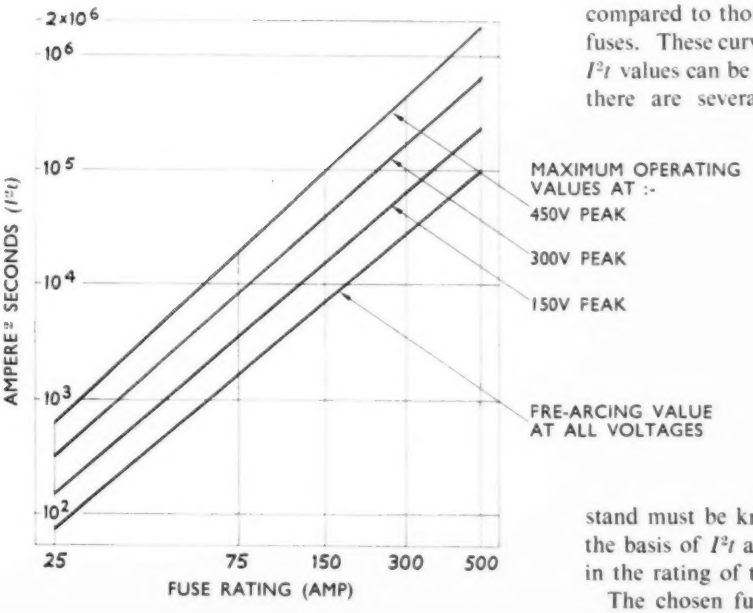
(c)

Fig. 18—Typical characteristics of fuses for the protection of semi-conductor rectifiers:

(a) I^2t prospective current characteristic

(b) I^2t voltage characteristic

(c) Current limitation



(b)

conditions, of a typical range of rectifier fuses compared to those of a typical range of industrial fuses. These curves demonstrate the order to which I^2t values can be reduced by specialised design, but there are several qualifications which must be made in achieving and applying them.

The worst condition that arises in practice is that which occurs when a cell in a rectifier bridge circuit breaks down and allows the healthy cells of an adjacent phase to conduct through it. A fuse in series with the faulty cell must restrict the I^2t to a value within the withstand of the healthy cells. Therefore this withstand must be known. Fuses are then chosen on the basis of I^2t and this is an essential parameter in the rating of the fuse.

The chosen fuse will have an assigned normal current rating based upon its temperature rise

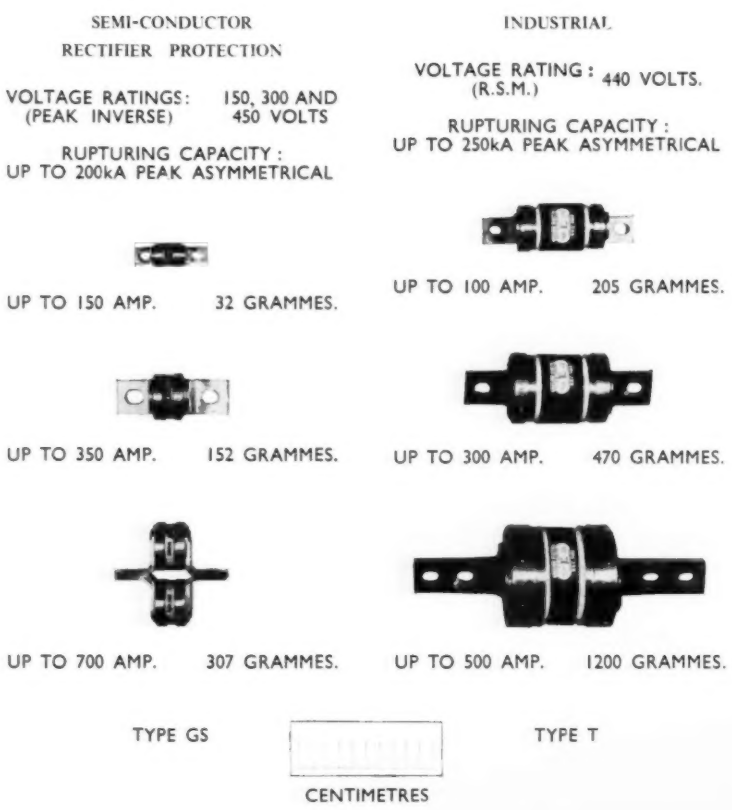

SEMI-CONDUCTOR
RECTIFIER PROTECTION
VOLTAGE RATINGS: (PEAK INVERSE) 150, 300 AND 450 VOLTS
RUPTURING CAPACITY: UP TO 200kA PEAK ASYMMETRICAL
UP TO 150 AMP. 32 GRAMMES.
UP TO 350 AMP. 152 GRAMMES.
UP TO 700 AMP. 307 GRAMMES.
INDUSTRIAL
VOLTAGE RATING: (R.S.M.) 440 VOLTS.
RUPTURING CAPACITY: UP TO 250kA PEAK ASYMMETRICAL
UP TO 100 AMP. 205 GRAMMES.
UP TO 300 AMP. 470 GRAMMES.
UP TO 500 AMP. 1200 GRAMMES.
TYPE GS
TYPE T
CENTIMETRES

Fig. 19—A comparison of size and weight of fuses used for semi-conductor rectifier protection and those for industrial use

limitations. Such ratings are determined by standard tests in which the fuses are connected to conductors rated at a given current density and mounted in free air. Correction factors may be applied for different mountings or ambient conditions. The rating of the chosen fuse may well determine the full load rating of the cell and its associated equipment.

The fuse must then be considered in relation to the applied voltage required from the equipment. Again, a semi-conductor cell is seldom used in service at voltages closely approaching its ultimate voltage withstand. Fuses are designed to produce arc voltages not exceeding twice their own voltage ratings without damage to the cells being protected. The arc voltage across a fuse is $L\frac{di}{dt}$, and being a function of the length of the arc is virtually independent of the applied voltage. This means that a fuse designed for a high applied voltage affords no protection to a cell rated for a much lower voltage. Hence it is necessary to have a choice from a range

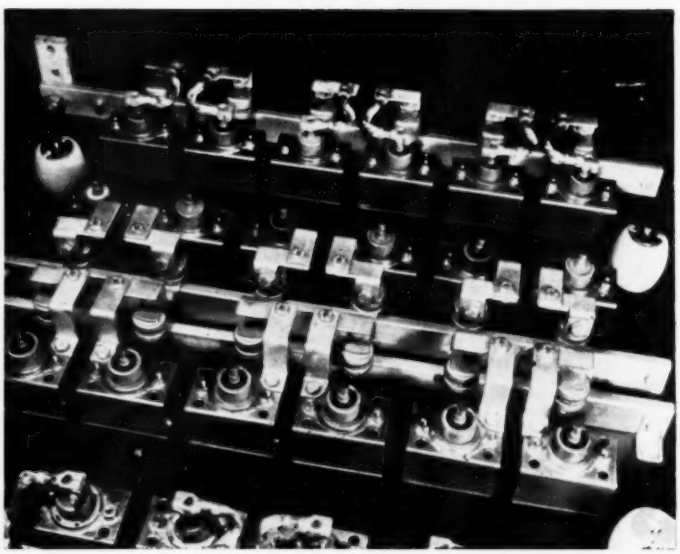


Fig. 20—100 A silicon cells individually protected by 300 A fuses in 750 kW equipment

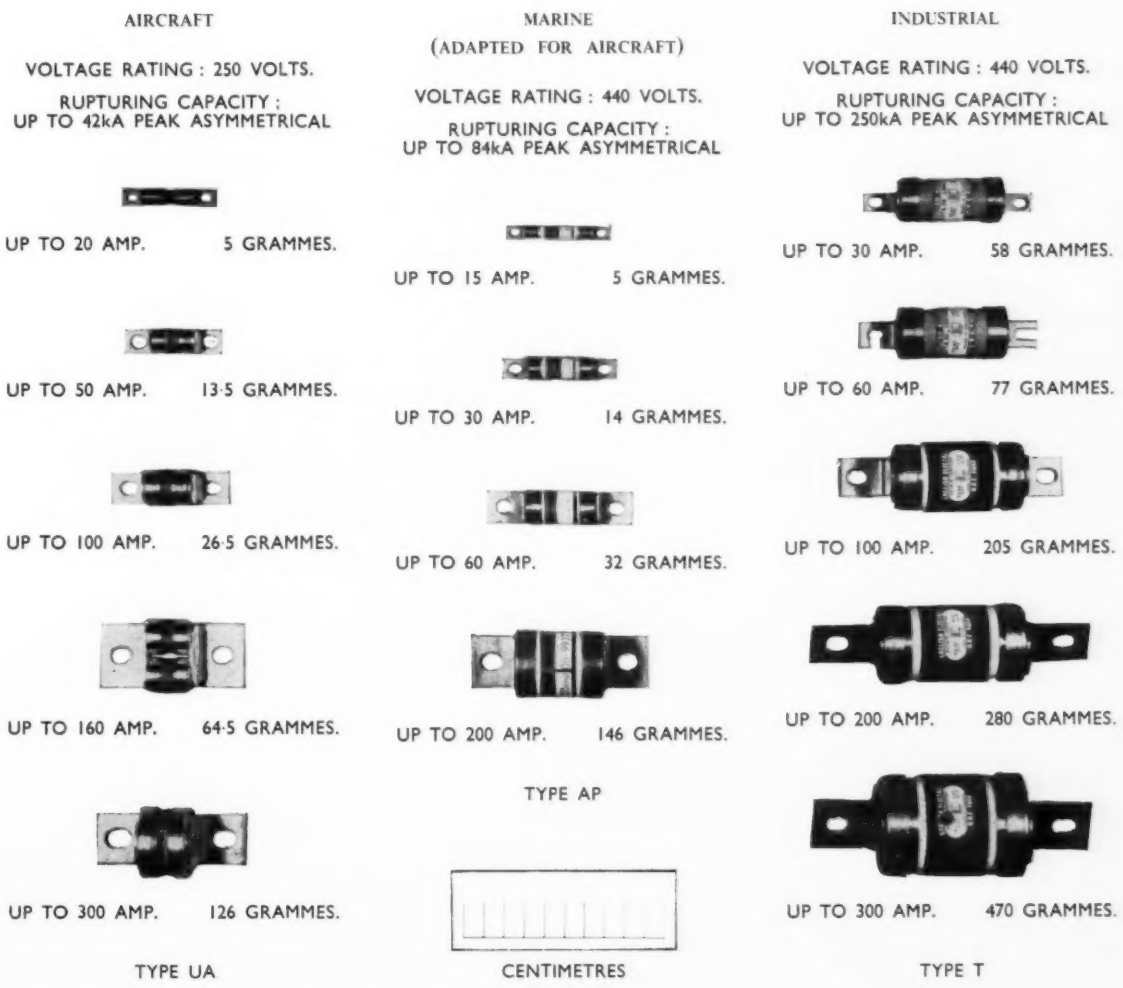

AIRCRAFT
VOLTAGE RATING : 250 VOLTS.
RUPTURING CAPACITY :
UP TO 42kA PEAK ASYMMETRICAL
UP TO 20 AMP. 5 GRAMMES.
UP TO 50 AMP. 13·5 GRAMMES.
UP TO 100 AMP. 26·5 GRAMMES.
UP TO 160 AMP. 64·5 GRAMMES.
UP TO 300 AMP. 126 GRAMMES.
TYPE UA
MARINE
(ADAPTED FOR AIRCRAFT)
VOLTAGE RATING : 440 VOLTS.
RUPTURING CAPACITY :
UP TO 84kA PEAK ASYMMETRICAL
UP TO 15 AMP. 5 GRAMMES.
UP TO 30 AMP. 14 GRAMMES.
UP TO 60 AMP. 32 GRAMMES.
UP TO 200 AMP. 146 GRAMMES.
TYPE AP
CENTIMETRES
INDUSTRIAL
VOLTAGE RATING : 440 VOLTS.
RUPTURING CAPACITY :
UP TO 250kA PEAK ASYMMETRICAL
UP TO 30 AMP. 58 GRAMMES.
UP TO 60 AMP. 77 GRAMMES.
UP TO 100 AMP. 205 GRAMMES.
UP TO 200 AMP. 280 GRAMMES.
UP TO 300 AMP. 470 GRAMMES.
TYPE T

Fig. 21—A comparison of size and weight of fuses for aircraft, marine (adapted for aircraft) and industrial use

of fuses of various voltage ratings as well as at various current ratings.

The next factor to be considered is that of rupturing capacity. Semi-conductor rectifier equipments tend to be large in some industrial applications and the prospective fault currents are correspondingly large. Fuses must therefore be designed for high prospective current values and proved by test. 250 kA (peak asymmetrical) is not an unusual value.

A variety of rectifier arrangements exist and fuses may be used in different positions in such arrangements. The duty of the fuse under both load and fault conditions will vary according to its position in the circuit.

Finally I^2t will vary as a function of both the applied voltage and prospective current. Where these differ from the tested values the true service values must be obtained by interpolation. Curves are necessary for this purpose and Figs. 18a,

18b and 18c are typical of the kind of data which is now available. Fig. 19 shows typical fuses compared to industrial fuses. Fig. 20 shows fuses fitted into a rectifier equipment.

Aircraft fuses

The increasing fault levels on some modern aircraft and the adoption of higher voltages have made the introduction of better short circuit protection imperative. The h.r.c. fuse has been adapted for this purpose and offers many advantages not available by alternative means.

The parameters of performance required in aircraft are unlike any which occur in other applications and it has been necessary to design fuses specifically for aircraft use. Obviously minimum weight is a ruling factor but this must be related to other aspects of performance. The rupturing capacity specified by the aircraft industry at the present time is 16,500 A r.m.s. symmetrical at 250 V a.c. and 16,500 A at 120 V d.c.

In Britain, aircraft fuses must comply with specified characteristics and withstand tests laid down by the Air Registration Board. These include : vibration tests over wide frequency bands, climatic, mould growth, tropical exposure, acceleration, crash landing and endurance tests. Also, in order to rate the fuse for various positions, either outside or inside the pressurised zones of the aircraft, research has been necessary regarding the effects of high altitude. The results of these developments can be seen in Fig. 21.

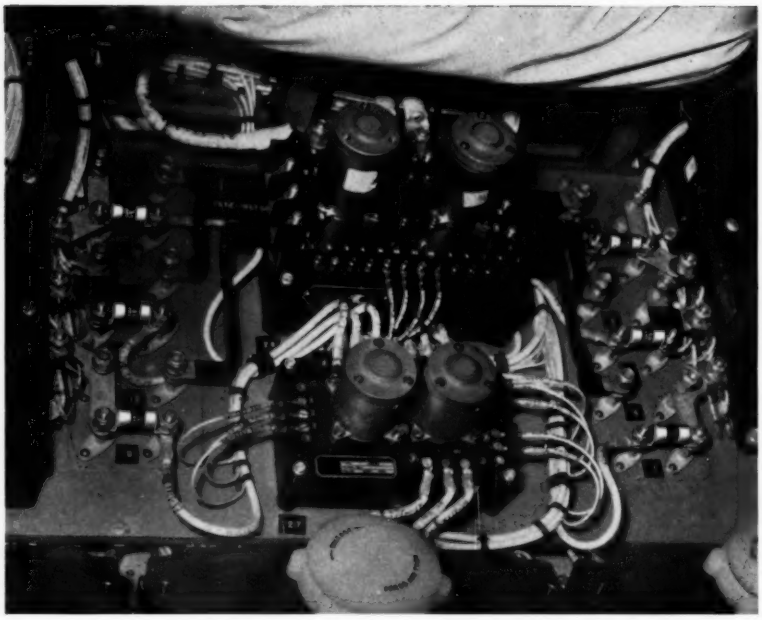


Fig. 22—H.R.C. fuses installed in a contemporary aircraft

Close attention to the characteristics required in relation to motor starting and other peculiarities of aircraft electrical practice has shown that the h.r.c. fuse is equal to other forms of protection in this respect. Moreover, the property of fault energy limitation becomes exceedingly significant in the case of aircraft protection. In civil aircraft in particular, the minimisation of fire risk from cables subjected to short circuit stresses is vital to the extent that no smoke or smell must be evident to alarm passengers. Research is still proceeding in this direction but the results so far achieved are in themselves sufficiently clear to commend the h.r.c. fuse for widespread applications. Fig. 22 shows an actual installation in a modern aircraft in which the specially designed fuses are in use.

A Gas Turbine for Peak Load Operation at the University of Alberta

DURING THE PAST TWELVE MONTHS an 'English Electric' 1,850 kW gas turbine generator set has been in service in a new Alberta Provincial Government power station at Alberta University, Edmonton, Canada. It is the first British gas turbo-alternator set in Canada, and it was chosen in preference to steam or diesel plant because of its advantages of compactness, lighter foundations, quick starting, and smaller cooling water requirements, and the ready availability of a local fuel—natural gas.

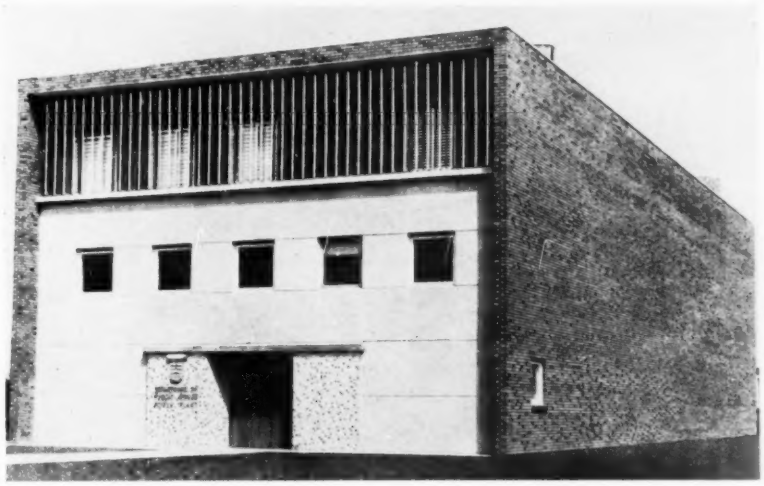


Fig. 1—The building housing the 'English Electric' gas turbine generator set at the Alberta University

A waste-heat boiler connected to the set provides heat for the University, a nearby hospital and the Provincial Auditorium. The proximity of the hospital to the new power station was a further reason for choosing a gas turbine as prime mover in preference to a diesel engine, the gas turbine being more readily silenced. It has been equipped by courtesy of the Provincial Government's Department of Public Works with a special instrument panel on which University students may make observations of performance.

The generating set has a site output of 1,850 kW at 59° F and 14·7 p.s.i.a. and is fuelled by natural gas taken from the City of Edmonton's supply system and compressed before being injected into the combustion chambers.

The waste heat boiler connected to the turbine exhaust generates 10,000 lb/hr of dry saturated steam at 10 p.s.i.g. when the turbine is operating at normal rated load.

In normal operation the turbo-alternator will run for eight-to-ten hours per day during the period of peak load. Its output is paralleled with the output of the existing steam generating plant and the City Electricity Supply system when feeding the adjacent University hospital, University buildings and Provincial Auditorium. During non-peak hours, the set acts as an emergency standby for hospital services.

The turbo-alternator

The 'English Electric' EM27 gas turbine

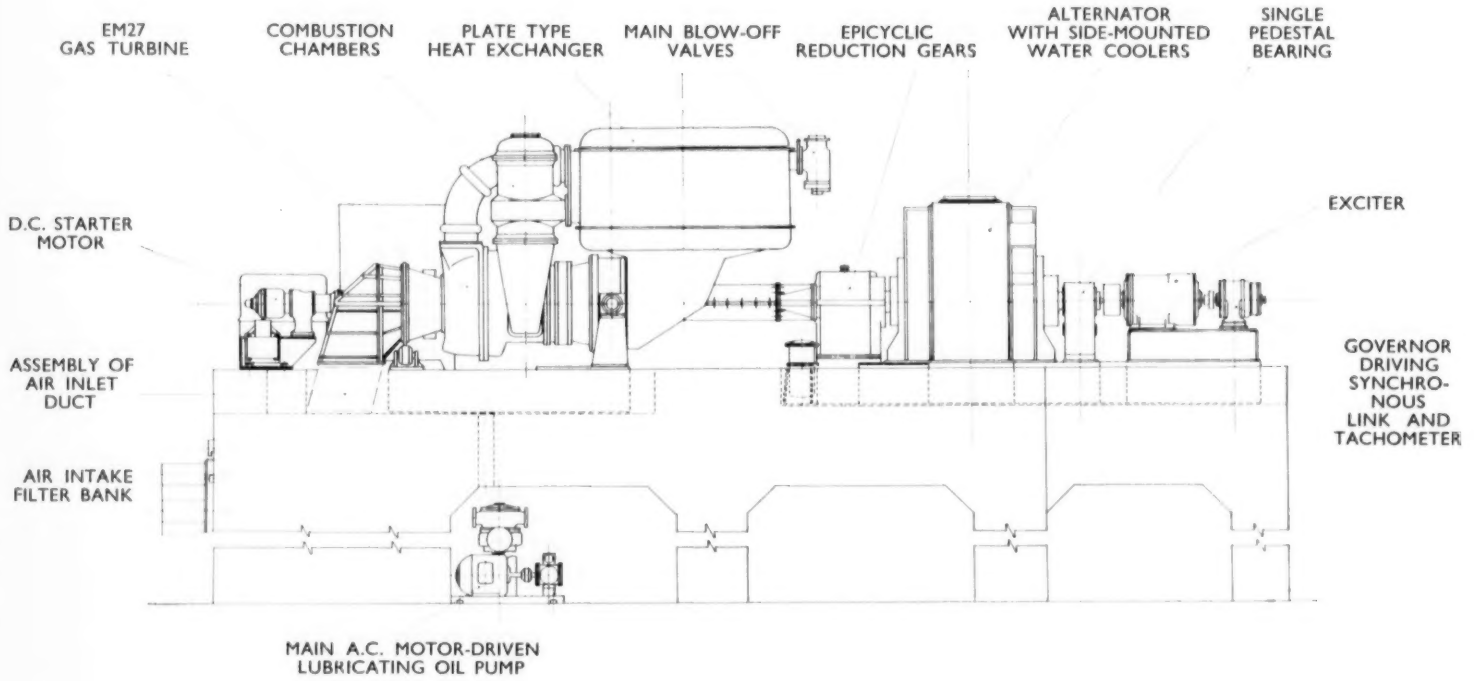
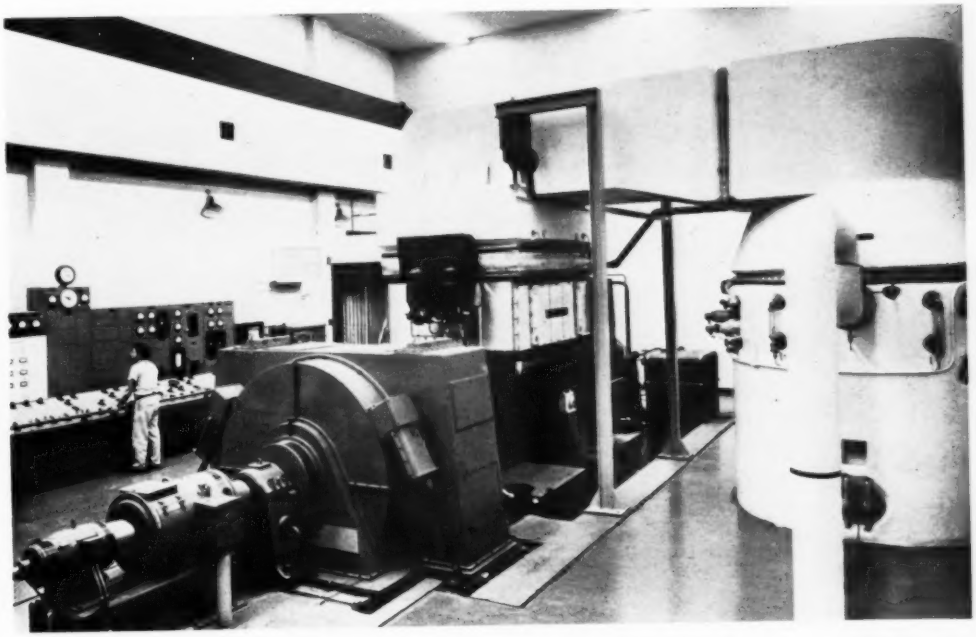


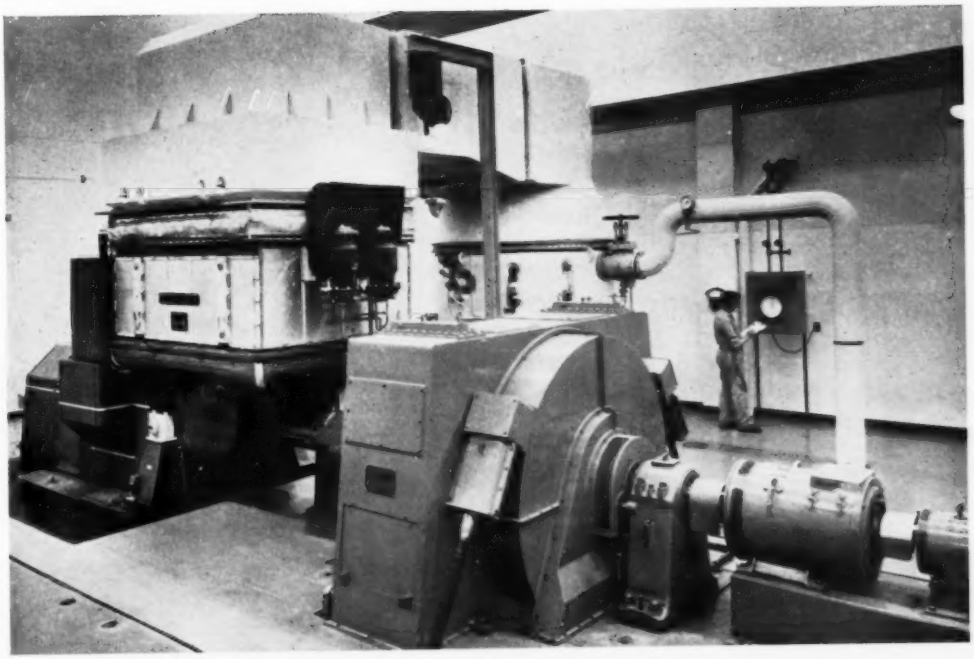
Fig. 2—General arrangement of the set, showing foundations and major items of equipment

PICTURES OPPOSITE :

Fig. 3 (Upper picture)—*Inside the power station. On the right of the generating set is the upper section of the waste-heat boiler. In the background are the control desk and the special instrumentation panel for the use of university students*

Fig. 4 (Lower picture)—*The 1,850 kW gas turbine alternator. Above the turbine itself can be seen the ducting leading to the waste-heat boiler in the background*





installed is an exceptionally compact two-shaft machine with twin combustion chambers. It is fitted with a standard plate-type regenerator (thermal effectiveness approximately 60%) which forms an integral part of the turbine assembly ; the method of mounting the regenerator eliminates the need for extra ducting and its addition does not increase the overall dimensions of the gas turbine.

The compressor has six axial stages followed by a single centrifugal stage giving a pressure ratio of 4·8 to 1 at a speed of approximately 8,200 r.p.m. under normal full load conditions. The compressor is driven by a direct coupled two-stage axial turbine with a design inlet temperature of 777°C (1,430°F). Power output is delivered by a mechanically separate two-stage axial power turbine revolving in contra-rotation to the compressor turbine at 7,000 r.p.m. This is coupled through flexible disc couplings to an Allen Stoeckicht 7,000/1,200 r.p.m. reduction gear. The low-speed shaft of the gear is solidly coupled to the 4·16 kV, three-phase, 60 c/s, 1,200 r.p.m. 'English Electric' alternator. Arranged for closed-circuit ventilation, the alternator has twin side-mounted water-cooled air coolers ; the salient pole rotor is supported at one end by the low-speed bearing of the reduction gear and at the other by means of a single outboard pedestal bearing, the exciter being direct-coupled to the free end of the rotor. The rating of the alternator has been fixed at 2,200 kW to allow for the increased power output of the gas turbine at low ambient temperatures.

Lubricating oil for the gas turbine, reduction gears and alternator is stored in the reservoir formed in the turbine baseplate. During starting, stopping and in normal operation an a.c. motor-driven pump supplies oil to the bearings, gears and the turbine oil-servo control system. In the event of a.c. failure a small d.c. motor-driven pump is automatically brought in to provide oil for bearing lubrication, while the turbo-alternator is being shut down. Lubricating oil cooling is carried out by a shell-and-tube type water-cooled heat exchanger. Filtration is provided on both suction and pressure sides of the oil pumps.

The turbo-alternator set is operated from a control desk situated at the side of the station, from which starting is accomplished by means of a push button which initiates an automatic starting sequence. Once this is in operation, control of the gas turbo-alternator set speed is achieved by means of an electrical synchronous link between the direct-driven exciter and the turbine governor.

Other features of the control system include a fuel-air ratio valve and temperature limiter which, by spilling servo oil and reducing pressure under the servo piston, control respectively the rate of acceleration and the maximum output of the turbine.

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